# Challenges of User-Centered Applications - Visualization on and Interaction with Arbitrary Display Environments

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*You see my kind of loyalty was loyalty to one's country, not to its institutions, or its office holders. The country is the real thing, the substantial thing, the eternal thing; it is the thing to watch over, and care for, and be loyal to; institutions are extraneous, they are its mere clothing, and clothing can wear out, become ragged, cease to be comfortable, cease to protect the body from winter, disease, and death. To be loyal to rags, to shout for rags, to worship rags, to die for rags–this is loyalty to unreason, it is pure animal; it belongs to monarchy, was invented by monarchy; let monarchy keep it.*
- A Connecticut Yankee in King Arthur's Court (Mark Twain)

# Abstract

Recent progresses and advances in the field of consumer electronics, driven by display technologies and also the sector of mobile, hand-held devices, enable new ways in presenting information to users, as well as new ways of user interaction, therefore providing a basis for user-centered applications and work environments.

My thesis focuses on how arbitrary display environments can be utilized to improve both the user experience, regarding perception of information, and also to provide intuitive interaction possibilities. On the one hand advances in display technologies provide the basis for new ways of visualizing content and collaborative work, on the other hand forward-pressing developments in the consumer market, especially the market of smart phones, offer potential to enhance usability in terms of interaction and therefore can provide additional benefit for users.

Tiled display setups, combining both large screen real estate and high resolution, provide new possibilities and chances to visualize large datasets and to facilitate collaboration in front of a large screen area. Furthermore these display setups present several advantages over the traditional single-user-workspace environments: contrary to single-user-workspaces, multiple users are able to explore a dataset displayed on a tiled display system, at the same time, thus allowing new forms of collaborative work. Based on that, face-to-face discussions are enabled, an additional value is added. Large displays also allow the utilization of the user's spatial memory, allowing physical navigation without the need of switching between different windows to explore information.

With *Tiled++* I contributed a versatile approach to address the *bezel problem*. The *bezel problem* is one of the Top Ten research challenges in the research field of LCD-based tiled wall setups. By applying the *Tiled++* approach a large high resolution *Focus & Context* screen is created, combining high resolution focus areas with low resolution context information, projected onto the bezel area.

Additionally the field of user interaction poses an important challenge, especially regarding the utilization of large tiled displays, since traditional keyboard & mouse interaction devices reached their limits. My focus in this thesis is on Mobile HCI.

Devices like mobile phones are utilized to interact with large displays, since they feature various *interaction modalities* and preserve *user mobility*.

Large public displays, as a modernized form of traditional bulletin boards, also enable new ways of handling information, displaying content, and user interaction. Utilized in hot spots, Digital Interactive Public Pinboards can provide an adequate answer to questions like how to approach pressing issues like disaster and crisis management for both responders as well as citizens and also new ways of how to handle information flow (contribution & distribution & accession). My contribution to the research field of public display environments was the conception and implementation of an easy-to-use and easy-to-set-up architecture to overcome shortcomings of current approaches and to cover the needs of aid personnel.

Although being a niche, Virtual Reality (VR) environments can provide additional value for visualizing specific content. Disciplines like earth sciences & geology, mechanical engineering, design, and architecture can benefit from VR environments. In order to consider the variety of users, I introduce a more intuitive and user friendly interaction metaphor, the *ARC* metaphor.

Visualization challenges base on being able to cope with more and more complex datasets and to bridge the gap between comprehensibility and loss of information. Furthermore the visualization approach has to be reasonable, which is a crucial factor when working in interdisciplinary teams, where the standard of knowledge is diverse. Users have to be able to conceive the visualized content in a fast and reliable way. My contribution are visualization approaches in the field of *supportive visualization*.

Finally, my work illuminates how the synthesis of visualization, interaction and display technologies enhance the user experience. I promote a holistic view. The user is brought back into the focus of attention, provided with a tool-set to support him, without overextending the abilities of, for example, non-expert users, a crucial factor in the more and more interdisciplinary field of computer science.

# Zusammenfassung


Aktuelle Entwicklungen im Bereich der Unterhaltungselektronik, vor allem im Bereich der Bildschirmtechnologien und auch im Bereich der mobilen Endgeräte (*smart phones*), eröffnen neue Wege dem Nutzer Inhalte zu präsentieren, und auch neue Formen der Interaktion.

In der vorliegenden Arbeit wird untersucht, wie verschiedene Bildschirm-Umgebungen genutzt werden können, um den Anwender hinsichtlich der Wahrnehmung von Information und auch der intuitiven Interation mit dieser zu unterstützen. Einerseits bilden neue Display-Technologien das Fundament für neue Visualisierungsansätze und auch kollaborative Arbeitstechniken, andererseits eröffnen die stetigen Neuerungen im Bereich der Unterhaltungselektronik, allem voran der Bereich der mobilen Endgeräte (z.B. Smart Phones, Handy, Tablet-PC), ein großes Potential die Benutzbarkeit und auch die Benutzerfreundlichkeit zu verbessern.

Sogenannte *Tiled display setups*, d.h. aus mehreren Einzelbildschirmen bestehende Monitormwände, vereinen eine große Bildschirmfläche und auch eine hohe Bildschirmauflösung. Dadurch wird es erleichtert sehr große Datensätze anzuzeigen und auch die Zusammenarbeit von mehreren Benutzern zu ermöglichen. Die Vorteile dieser Bildschirmumgebungen gegenüber herkömmlichen Desktop-Arbeitsumgebungen, die für einen Anwender konzipiert sind: mehrere Nutzer können gleichzeitig Inhalte erfassen, neue Formen des kollaborativen Arbeitens werden ermöglicht. Inhalte können sofort diskutiert werden, diese soziale Komponente ist ein deutlicher Mehrwert gegenüber klassischen Desktop-Arbeitsplätzen. Auch das räumliche Gedächtnis kann bei großen Bildschirmen genutzt werden, durch physikalische Navigation. Der Anwender muss also nicht mehr, wie bei Desktop-Systemen üblich, zwischen verschiedenen Ansichten wechseln, wenn er bestimmte Inhalte erfassen möchte, vielmehr kann er den *human zoom metaphor* nutzen.
Der *Tiled++* Ansatz bietet eine skalierbare Lösung um das sogenannte *bezel problem* zu minimieren. Dieses *bezel problem* ist vergleichbar mit dem Effekt eines *Stulpfensters*: der Fensterrahmen beschneidet die Aussicht und verdeckt somit einen Teil des Bildes. Dieser Effekt ist bei bisherigen Flüssigkristallbildschirmen (Liquid Crystal Display, LCD) unvermeidbar, da die Ansteuerungselektronik in den Rahmen der

Monitore untergebracht ist. Bei dem *Tiled++* Ansatz wird durch die Kombination von zwei Displaytechnologien, ein großes *Focus & Context* Display geschaffen: die LCD Geräte bilden dabei den hochauflösenden Fokusbereich, den Kontextbereich bilden die Monitorrahmen, auf die mit Hilfe eines herkömmlichen Projektors Kontextinhalte, mit einer niedrigeren Auflösung, projiziert werden.
Zusätzlich ist der Bereich der Mensch-Maschine-Interaktion eine wichtige Herausforderung, gerade im Bezug auf große Monitorwände, da eine klassische Tastatur & Maus-Interaktion ihre Grenzen erreicht hat und die bereits angeführten Vorteile torpedieren würde. Der Fokus liegt hierbei auf mobilen Endgeräten, da sie sowohl über verschiedene Interaktionmodalitäten verfügen und gleichzeitig die Mobilität des Anwenders nicht einschränken.

Große, öffentliche Bildschirme, eine modernisierte Variante von Pinnwänden, bieten neue Wege mit Informationen umzugehen, Inhalte anzuzeigen und auch neue Wege der Mensch-Maschine-Interaktion. Eingesetzt in *Hotspots* bieten diese Digitalen Interaktiven Öffentlichen Pinnwände (Digital Interactive Public Pinboards) eine adequate Antwort auf die Frage wie man dringlichen Fragen, beispielsweise dem bereitstellen von wichtigen Informationen für Ersthelfer und Bürger in Katastrophen- und Krisengebieten, begegnen kann. Weiterhin bieten öffentliche Bildschirme innovative Wege des Informationsflusses (Information hinzufügen & Information verbreiten & Information zugänglich machen)in Büroumgebungen.

Virtuelle Realität (VR) ist eine Nische im Bereich der Visualisierungsansätze. Die Nutzung der VR kann jedoch, je nach Anwendungsbereich, einen gewissen Mehrwert für die Anwender darstellen. Im Rahmen dieser Arbeit wird anhand eines Anwendungsbeispiels aus dem Bereich der Geowissenschaften/Geologie aufgezeigt, in wie weit diese Fachrichtung von der VR profitieren kann.

Die Herausforderungen im Bereich der Visualisierung basieren auf der Fähigkeit komplexe Inhalte so abzubilden, dass die Lücke zwischen Verständlichkeit der Information und Informationsverlust möglichst gering ist. Die verständliche Darstellung von Inhalten ist besonders wichtig in interdisziplinären Gruppen, in denen ein unterschiedlicher Wissensstand herrscht. Die Anwender müssen in der Lage sein, die visuell aufbereiteten Informationen schnell und sicher erfassen zu können.

Die vorliegende Dissertation beleuchtet die Synthese der Bereiche Visualisierung, Mensch-Maschine-Interaktion und aktueller Bildschirmtechnologien und rät zu einer ganzheitlichen Betrachtung der Teilaspekte, hinsichtlich einer Verbesserung der Benutzerfreundlichkeit. Der Anwender rückt wieder in den Fokus der Aufmerksamkeit, ausgestattet mit Werkzeugen die ihn bei seinen Aufgaben unterstützen, ohne ihn zu überfordern. Mit dieser Vision kann Anwendern anderer Fachrichtungen, ein essentieller Faktor im stetig interdisziplinärer werdenden Bereich der Informatik, Rechnung getragen werden.

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# List of Abbreviations

| | |
|---|---|
| ANOVA | Analysis of Variance |
| API | Programming Interface |
| ARC | VR Radial Menu (derived from arc geometry) |
| BauGB | Baugesetzbuch |
| CAVE | Cave Automated Virtual Environment |
| CPU | Central Processing Unit |
| DIN | Deutsche Institut für Normung e. V. |
| DIP | Digital Interactive Pinboard |
| DIPP | Digital Interactive Public Pinboard |
| FBC | Form-Based Code |
| GeoRSS | Web feed |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GPU | Graphics Processing Unit |
| GUI | Graphical User Interface |
| HCI | Human-Computer Interaction |
| HD | High Definition |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISO | International Organization for Standardization |
| LAN | Local Area Network |
| LCD | Liquid Crystal Display |
| LIDAR | Light Detection and Ranging |
| mHCI | mobile Human-Computer Interaction |
| MS Code | Microsoft Code Tag |

| | |
|---|---|
| NASA | National Aeronautics and Space Administration |
| NOSA | NASA Open Source Agreement |
| OS | Operating System |
| PC | Personal Computer |
| PRD | Product Requirement Document |
| QR Code | Quick Response Code Tag |
| SDK | Software Development Kit |
| SRS | Software Requirement Specification |
| THW | Technisches Hilfswerk |
| UHI | Urban Heat Island |
| USAID | US Agency for International Development |
| USGS | United States Geological Survey |
| VIP | Visualization, Interaction, Presentation |
| VRUI | Virtual Reality User Interface |
| VR | Virtual Reality |
| WAN | Wide Area Network (Internet) |
| WIFI | Wireless Local Area Network (WLAN) |

# Chapter 1

# INTRODUCTION

## 1.1 Motivation

Advances in both hardware technologies and application driven approaches provide computer scientists as well as users from other disciplines with new powerful toolkits, apt to enhance usability and therefore the user experience. Multi-core central processing units (CPUs) as well as powerful graphic processing units (GPUs) facilitate the processing of large datasets and provide the computational power to visualize and display them on the display device of choice.

In addition to advances have not been limited to CPU and GPU developments, also the fields of display technologies as well as the fast growing field of mobile devices, namely smart phones, tablets has been pressing forward in recent years. Prices for both projector hardware and Liquid Crystal Displays (LCDs) have dropped significantly, the market for 3D technology advanced, making 3D television technology available to the commercial market, at reasonable prices. Mobile phones also have become more versatile, offering more interaction modalities and more extensive functionality, making them suitable for utilization as interaction devices.

The application field of Urban Planning is an interdisciplinary field, incorporating multifaceted operational aspects. Alongside traditional planning aspects, both social aspects and environmental aspects are becoming more important and have to be taken into consideration. Therefore classic planning instruments have reached their limits in terms of processing the multi-dimensional information and utilization of it in today's complex planning processes. In this context the adequate visualization and representation of data is crucial. Computer Science can provide both applications and work environments, capable of supporting planners in crucial tasks, for example data mining, spotting correlations within large data sets, conveying complex information to stakeholders and collaboration between stakeholders.

Considering typical planning workspace environments, namely single user workspaces, serious limitations become obvious: single user environments (e.g. desktop PCs) fail to display all the required information simultaneously, without losing context. Limited resolution and restricted screen real estate on single user workplaces render them unsuitable for collaborative work, therefore making new display technologies an appealing option. Emerging new display technologies, such as tiled display setups, are designed to overcome these shortcomings. They combine large screen real estate with high resolution screens, room for establishing a collaborative workspace environment, and additionally are a cost-efficient solution.

Other disciplines and application fields, like earth sciences also are demanding user friendly systems in order to efficiently process information and get support to complete tasks.

In order to create applications as well as suitable work environments, evolving around the user's needs, it is up to the field of computer science to collaborate with users from the specific disciplines to formulate, design, evaluate and implement user-centered applications and work environments.

## 1.2 Distinction of focus

Regarding the technical basis, the emphasis of this thesis is on three display environments. Display technologies provide the basis for both new interaction metaphors as well as collaborative work environments. In addition they also provide for new ways of information visualization and also can enhance the user's perception.

(a) LCD-based tiled display walls.

(b) Public Displays.

(c) Virtual Reality Environments (CAVE).

On the one hand this choice has been influenced by the technologies being available for research. On the other hand the display environments offer a variety of possibilities, especially regarding visualization and interaction metaphors. Furthermore they offer the possibility to demonstrate the versatility to suit the different needs of users from various disciplines. The choice of display environment should be made accordingly to suit the user's needs in order to provide a maximum of benefits for task completion.

The visualization metaphors introduced and implemented in this doctoral thesis have one thing in common: easy comprehensibility. A good visualization should transport the important information in a straight forward and understandable way, bridging the gap of comprehensibility and information content. By doing so, the diversity of user groups is taken into consideration. Interdisciplinary teams gain importance, therefore visualization approaches have to consider different fields of expertise as well as diverse levels of knowledge. The visualization should help users in perceiving the represented content, support analysis tasks, data mining, shortly said: make the user's life more convenient and reliably convey the needed information.

Human-Computer Interaction principles focus on user interaction, the way of how an user can interact with digital content. Interaction should be fluid, intuitive, easy to learn (short training period) and not overwhelming the user by designing cumbersome interaction interfaces or interaction metaphors [Mil55]. Having the needs and the tasks of users in mind, as well as considering the work environment, the link between user and machine can be designed. The focus is on mobile interaction devices, also accommodating the common availability and popularity of these devices. Basic knowledge on how to operate mobile devices (e.g. smart phones, tablets) can be presumed, so basic interaction tasks can be performed by the majority of potential users, using their own interaction and storage device. In addition hand-held devices facilitate the user's mobility, a crucial factor of collaborative work environments.

With the careful choice of display technology, visualization and interaction, user-centered applications and work environments can be developed. In summary: users have to benefit from all aspects of the approaches. The approaches should support the users in accomplishing the intended tasks, not hinder them by making things even more complex and cumbersome. The user should be in focus of design, and the design should consider aspects of usability, as well as common sense.

## 1.3 Thesis structure and Methodology

This thesis deals with the synthesis of the aspects display technologies, visualization and human-computer interaction. The combination of these elements in a meaningful way, namely in order to support users in specific tasks and provide for adequate work environments, will lead to an enhanced user experience and therefore improved usability. In this thesis I strongly promote a holistic view, in order to enhance the user experience and to create user-centered applications and work environments.

The focus of *Chapter 2* is on display technologies. In this chapter an overview of recent developments in the field of display technologies is provided and three display technologies are introduced in detail, in particular LCD-based tiled display environments, public displays and Virtual Reality environments.

*Chapter 3* deals with the important (but often neglected) field of user studies and evaluations. My contributions to the important field of user studies are two evaluation approaches, conducted during this thesis. The first evaluation approach has been conducted after the implementation of the Tiled++ prototype, in order to gain insight on both the perception effects of the approach, as well as the effects on user interaction. A second evaluation has been conducted during the concept & design phase for creating an user-centered Graphical User Interface (GUI) for Virtual Reality (VR) environments. Furthermore a method to measure *subjectivity*, in order get a deeper understanding of the user's experience during evaluation tasks, is introduced.

My new ideas of interaction principles and techniques are presented in *Chapter 4*. Interaction metaphors and approaches out of the field of mobile Human-Computer Interaction (mHCI) are applied to large tiled display environments, as well as Public Display environments. mHCI offers the advantages of maintaining both *user mobility* and *multi-user interaction*. In addition, I introduce a new concept of an user-centered, scalable and intuitive GUI for Virtual Reality environments.

In *Chapter 5* I introduce visualization metaphors, developed to suit the needs of users from the application fields of Earth Sciences, Urban Planning and Disaster management. *Supportive visualization* approaches are presented in detail and are used to clarify the requirements, which users from different disciplines have.

In *Chapter 6* I present three user-centered applications/approaches, fusing the aspects display technologies, visualization metaphors and interaction techniques. Each approach is tailored to suit the needs of a specific user group, in order to ensure usability. The *holistic view*, promoted by me, is an essential approach to develop user-centered applications and work environments.

With *Chapter 7* I conclude this thesis by outlining the core findings and also providing an outlook about future research possibilities & open challenges.

## 1.4 Contribution

My contributions presented in this thesis are:

With the *Tiled ++* approach, I introduce a seamless LCD-based tiled display setup. Seamless in the sense of *semantic loss*, by addressing the french window effect, also known as the *bezel problem*. Users are now able to perceive a seamless picture without the typical problems of information loss (*overlay*) or deformed picture (*offset*). In addition, the evaluation I conducted after the implementation of *Tiled ++* proved how useful the added information is, especially during navigation and perception tasks. Tiled high-resolution display walls also proved to be a fruitful option for collaborative work scenarios. They offer enough physical space, in order to let multiple users explore content, as well as interacting with the displayed content. The utilization of tag codes, makes a contribution to the field of interaction with large display environments. My contribution features the utilization of mobile devices to interact with large, wall sized displays, enabling multiple users to interact with content and also enabling immediate face-to-face discussions. This is a crucial factor in the field of urban planning (just to name one example), where stakeholders with diverse backgrounds have to be integrated into complex planning processes. Stakeholders can benefit from the synthesis of large display, intuitive user interaction and user friendly, easy accessible visualization during public participation processes, decision making and planning support.

In the field of public displays, capturing and enhancing the idea of traditional billboards, I demonstrate new ways of deploying public displays in public spaces, *hot spots*. In office environments public displays can be an alternative to paper and email notifications, providing ecological value and reducing network traffic by avoidance of sending out mass emails. With a public display, a so called **D**igital **I**nteractive **P**inboard (DIP) users are able to share content in an office environment and pick up the information of interest, whenever they feel to. My approach returns the gift of self determination to users. With the DIP approach users can decide which information they want to share, save and download. Furthermore the *hot spot* location of the DIP can be a meeting point for social interaction. The **D**igital **I**nteractive **P**ublic **P**inboard (DIPP) is an advanced version of a public display, enhancing the basic principles of the DIP and offering an application tailored to suit the needs of first responders and citizens after natural or man-made disasters. My idea of deploying interactive public displays for disaster management, derived from the fact that many first responders, especially after the Haiti and Japan earthquakes did find themselves lost, after arrival in the airport. No one did coordinate and provide information to arriving helpers. With the DIPP system, users are able to obtain basic information and interact with the public screens, using their own mobile devices and a wireless connection. The DIPP approach combines the elements of deploying a display technology with elements of intuitive, straight forward user interaction (dual screen) and the icon-based visualization approach, considering the needs of the diverse group of users.

My contribution to the field of Virtual Reality (VR) environments is a tool to simulate terrestrial Light detection and ranging (LIDAR) scans, using the VRUI framework, therefore being scalable and not limited to VR environments, only. Terrestrial LIDAR scans are time consuming since the laser scanners have to be set up in the field, accurately. If not set up correctly, the problem of *shadowing* can occur: the scanner's view is obstructed and therefore no point cloud data of the blocked area can be recorded. Contrary to the problem of insufficient point cloud data, with *oversampling*, meaning to obtain more than needed samples (scan tasks) of a certain area, also this issue is addressed. With the LIDAR simulation tool I address both problems (shadowing & oversampling) by providing a tool to simulate the terrestrial scans in a virtual environment, based on lower resolution aerial LIDAR data, which is commonly available. Users can choose from terrestrial scanner presets and simulate the scans, therefore saving time and being able to get maximum benefits out of their actual field-trip time in the real world environment. Furthermore the GUI of the VRUI framework has been re-designed, based on the findings of a informal evaluation, to spot deficits, during the design process. My *ARC* GUI concept offers better scalability on arbitrary display environments and also addresses precision issues, especially when using the flightstick device for interaction in Virtual Reality environments. Furthermore the *ARC* concept considers the human field of view and in addition contributes to the design of ergonomic virtual work place environments.

My thesis emphasizes the importance of a **holistic view**, when designing user-centered applications and user-centered environments. By careful choice of display technology, visualization and interaction metaphor, as well as consideration both user and task requirements, real user-centered applications and environments can be developed. With the increased importance of interdisciplinary approaches a holistic view becomes crucial. Considering only partial aspects of applications or environments (e.g. focussing solely on visualization aspects), can't be considered contemporary, since only one aspect is taken into consideration.

# Chapter 2

# ENHANCING NEW DISPLAY ENVIRONMENTS

## 2.1 Introduction

With continuous advances in the field of display technologies as well as graphic accelerators, computer science has been able to address one of the core problems of information and scientific visualization. Visualization approaches always have been limited by both resolution and screen size, but with the common availability of projector technologies, **L**iquid **C**rystal **D**isplays (LCDs) and advances in both CPU (central processing unit) and GPU (graphic processing unit), making the technologies available at reasonable prices, the development of building high-resolution tiled display walls has been fostered.

Both projector-based, as well as LCD-based tiled display approaches combine large screen real estate with a moderate (projector-based) to high (LCD-based) resolution. The pixel density [1] of common LCDs is higher, compared to common projectors. With the upcoming of **H**igh **D**efinition (HD) projectors (1080p, offering a resolution of 1920 x 1080) the gap to LCDs is reduced, but not closed.

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[1] pixel per inch (ppi)

When setting up a projector-based tiled display, users have to be aware of the calibration issues coming along with this specific kind of tiled display. Not only in the sense of geometric calibration, the users also have to calibrate them regarding luminance and color uniformity. The projectors have to be calibrated very carefully, in order to achieve a basic geometric calibration (lens distortion, key stone effect). Luminance and color calibration is a demanding task, especially if the goal is an uniform, seamless projection. Generally speaking, projector-based approaches are more expensive, regarding price of projectors, limited operational life span of projector lamps (all projector lamps should be replaced at once, if one reaches the end of the life cycle), as well as overall maintenance efforts (setting up a proper rack, geometric calibration). At CeBIT 2012, BenQ [2] introduced laser-based projectors (BlueCore light engine), extending the maintenance free life span up to 20000 hours of operation.

Liquid Crystal Displays offer a more convenient way to set up a high-resolution tiled display wall. A basic geometric calibration can be achieved by choosing a proper rack to mount the displays. LCD prices dropped and are now commonly available at reasonable prices. Achieving a basic luminance and color calibration is not that demanding, if directly compared to projector-based approaches.

Public displays also have become very popular. In cities public displays are utilized for advertisement and signage purposes, in airports news and flight plans are displayed for visitor information and guidance. Some public displays also invite users to interact with them, but these displays are rare and usually serve as an information kiosk with limited interaction possibilities.

With the rise of mobile human-computer interaction the possibilities of utilizing public displays has increased. Users are able to interact with their own mobile devices on the fly, if they pass a public display and spot something of interest.

**V**irtual **R**eality (VR) environments always have been a very specialized niche. Commercial applications of 3D display technologies are gaining attention in the area of both cinema and home cinema, making the 3D technology known to a broad public. Attempts to make 3D hardware tempting to the gaming community have not been

[2] http://www.benq.de/

crowned with success. Current problems with 3D hardware is, that 3D perception snaps off in the border areas of the screens and that some display types demand special viewing angles or even additional hardware (e.g. shutter glasses).

The utilization of Virtual Reality environments for scientific purposes also has to be observed critically. Not every discipline can benefit from the visualization and interaction possibilities VR environments, e.g. a **C**ave **A**utomatic **V**irtual **E**nvironment (CAVE), can offer. Designated application fields, e.g. Earth Sciences, profit from the visualization and interaction capabilities; since some of the data is *native* 3D data, the rehashing of it is readily comprehensible. In other fields, like architectural visualization the rehashing of 2D CAD plans or even 3D geometry is more time consuming, due to file compatibility. In addition the visualization has to meet certain visual standards (key word: *photorealism*), which VR, in most cases, is not able to provide. Furthermore users have to struggle with interaction in VR as well as the limited availability of CAVEs.

## 2.2 State of the Art

Display devices always have been a crucial part of computer hardware. On displays the information is displayed and therefore it is the direct link between visualization and the user's perception. Some display technologies can support user perception, depending on the task.

An overview of various display technologies supporting user perception is provided in the work of Baudisch et al. [BDDG03]. The *focus & context* screen approach of Baudisch et al. is described in detail in [BGS01] and evaluated in [BGBS02]. The *focus & context* approach consist of two display technologies: a large projector based display, with a cut-out space for a regular computer screen. The projector image is providing low resolution context information where the display is providing focus information at a higher resolution. The advantage of this approach is that the user can utilize his peripheral vision and can keep the things in context, which usually would be outside his vision.

Ebert at al. enhance the original idea of the *focus & context* screen in their approach. They introduce a *2D+3D Focus+Context* screen [EDD+08].

With *Pileus* an uncommon display device is presented [HMO07], [MH09]. The authors propose an umbrella display for augmenting reality. The concept of *Pileus* can be transferred to other tangible everyday-life objects, creating new ways for Augmented Reality (AR). Lee et al. [LHT08] take up the umbrella idea and extending the amount of *foldable displays*. 4 types of foldable displays are presented, each one suiting specific needs of the user, regarding display size and display shape. The problem of users being bound to more or less static, rectangular displays is addressed with this approach.

The field of tiled displays has been a very popular field, since tiled display setups offer various advantages to the users. Czerwinski et al. provide a general overview of large display research [CRM+06]. Cognitive benefits of large display environments are pointed out, but also open research questions regarding usability issues with large display environments are presented.

Hereld et al. provide a tutorial on how to build a projector based tiled display wall [HJS00]. Hereld et al. also introduce *CupHolder*, a tiled display approach to suit the needs of high-resolution, large screen surface and collaborative & interactive work environments [HPBS06]. A guide on how to create cost-efficient LCD-based tiled display walls is provided by Navrátil et al. [NWJ+09].

The work of Ni et al. [NSS+06] expose the ten major research challenges in the field of tiled display environments, with the creation of really seamless tiled display walls ranking as the *number one* research challenge.

The work of Ball [Bal10] provides a trenchant insight on how large displays are the determining factor in improving productivity. Bi and Balakrishnan [BB09] also have been focusing on the impact of large displays compared to traditional single or dual display environments.

Already mentioned as the *number one* research challenge [NSS+06], the bezel problem also is topic in the work of Bi et al. [BBB10]. The bezel problem also is addressed by Mackinlay and Heer [MH04]. They present seam-aware applications, enhancing user perception when facing the visual gap of the display seams. *Mouse*

*Ether* [BCHG04] also addresses the warping effects when the mouse cursor is crossing from one display to another.

Frameworks to drive tiled display environments are presented by Bierbaum et al. [BJH+01]. The authors introduce *VR Juggler*, which is used as a common basis for application development and prototyping on arbitrary display environments similar to the VRUI framework [3], developed at UC Davis, CA, USA. *SAGE*, a framework to drive tiled display setups is presented as a learning and collaboration environment by Delgado et al. [DJS+09]. Humphreys et al. [HBEH00] introduce *WireGL*, a scalable system that allows applications to be rendered on tiled display setups. WireGL was preceded by the work done by Humphreys and Hanrahan [HH99] were a distributed rendering system driving a 6 x 2 projector based tiled display has been created in order to support collaboration within work groups. 2002 Humphreys et al. introduced *Chromium* [HHN+], which has been very popular in driving tiled display setups. With *JuxtaView* an application to distribute and display very high-resolution datasets on tiled display setups is presented [KVV+04].

Jaynes is giving insight on the future of easy-to-assemble large, high-resolution displays. He is pointing out the advances for the field of computer graphics as well as the human-computer interaction community arising from these new display systems, offering nearly unlimited scalability in terms of size and resolution [Jay07].

An Approach to synchronize LCD-based tiled display environments is introduced by Deshpande [Des09].

Ponto et al. introduce *VideoBlaster* a low bandwidth network method for displaying multimedia content on tiled wall system [PWD+09].

There are various ways to create tiled display environments. Projector-based tiled displays have to be considered as the more intricate display environments, regarding calibration and also cost-efficiency (*pixel per $* formula). Schikore et al. [SFF+00] and Brown and Seales [BS02] present approaches to projector based tiled display environments. Another projector-based approach to tiled displays is shown in the work of Chen et al. [CCL+01]. The aspects of data distribution on high-resolution displays are shown in the work of Chen et al. [CCF+01]. The method of manufac-

[3] http://keckcaves.org/software/vrui

turing and using projector-based tiled displays is explained in the work of Bordes and Pailthorpe [BP04]. Multiple displays are used to create a VR environment by Chiba et al. [CIS08]. Calbration of projector-based tiled wall systems is more complex than calibrating LCD-based tiled walls. An automatic alignment of multi projector displays using un-calibrated cameras is presented by Chen et al. [CCF+00]. Chen et al. [CSWL02] are using Homgraphic Trees for a basic geometric alignment of projector-based tiled wall displays. Lee et al. [LDMA+04] present an approach to automatically calibrate projectors by using embedded light sensors. Wallace et al. [WCL03] also dispute the problem of calibrating projector based tiled display setups and offer an algorithm for color calibration. They designate three major issues with calibrating projector based environments: calibration of geometry, calibration of luminance and color calibration. The distinction of problems regarding color and brightness also was done in the work of Stone [Sto01]. Majumder and Brown provide an overview of all important aspects of multi-projector display setups. Topics like alignment, geometric calibration, and seamlessness regarding color calibration are covered in detail [MB07]. The main problem of projector based tiled display systems, achieving a photometric seamless display, has been addressed in the work of Majumder and Stevens [MS04], [MS05]. Jaynes et al. present an approach to remove shadows, caused by users interacting with front-projection tiled display systems [JWS+01]. Bhasker et al. present advances in the field of multi-projector display environments [BJM07].

Displays, set up in public places for art, entertainment or serving as information kiosk, have been popular for years.

Antonaki [Ant08] describes how technologies will become a part of our everyday life. The main question in this connection, how these technologies change our life and influence our vision.

Chahine et al. [CCDY09] visualize user interaction with a public map, and displaying it on a public screen, in this way creating *Public Art*. *BlogWall* is another innovative approach to make use of public displays in an artistic way. Users can communicate with the display by sending short message service content to the display by using a given number, and the message text then is displayed in an animated way, creating public poem art.

*eCell* [BI05], meant for collaborative work in a school environment, offers two displays: a private display and a public display, facilitating collaborative work and social contacts between the pupils .

In the work of Vogel and Balakrishnan [VB04] a public display environment is developed for sharing information, featuring gesture interaction.

A *Interactive Electronic Wireless Billboard* is implemented by Lui et al. [LHC04]. The focus of the featured system product advertisement and electronic purchase options via a Blue tooth connection, which enables interaction possibilities with the billboard.

Haritaoglu and Flickner [HF01] developed a system for advertisement billboards which captures the attention users are giving the billboard. This information then is used to be able to show advertisements in a more effective way, by determining user groups and target audience.

Although not being a public display in the traditional sense, the *Rotating Compass* approach of Rukio et al. is related to the wide field of public displays. Their approach features a novel display type, providing navigation support to users, in combination with the user's mobile phone [RMH09]. Müller et al. [MJKK08] also propose the combination of public displays and mobile technologies for pedestrian navigation.

*Info Canvas*, developed by Miller and Stasko [MS01] is an ambient display for use in office environments to paint and save interesting information. One can describe the approach as a ambient bookmark in order to remind the user in an unobtrusive way.

Kaviani et al. [KFF$^+$09] propose a public display featuring mobile phone interaction, combining both large screen real estate and smaller display of the mobile phone. They try to address the problems of user interaction resulting from large screen surfaces by shifting parts of the screen to the mobile phone display, therefore creating an interactive dual display.

*Kimono* [HPR05], a public display is used for sharing information. The authors not only provide a static source of information and knowledge, they also give the user the ability to interact with the information provided, by adding and saving information with a mobile smart device, such as a PDA or a mobile phone.

Dalsgaard et al. [DDE08] propose the usage of public displays in public knowledge institutions, like museums. Visitors actively can participate with the system and therefore experience knowledge in a different way. *Info Gallery* [GRSBP06] is an information support system for visitors of physical libraries. The web based infrastructure features streams and recent information, like background information on recent exhibitions, to enrich the experience visitors have in the library.

*Plasma Posters*, introduced by Churchill et al. [CND+04], feature interactive public displays showing information content in an office environment. The authors show, that the public, digital poster have become part of the regular email or web-based sharing of information. With *eyeCanvas* Churchill et al. enhance the *Plasma Poster* approach by adding user interaction and setting up the public display in a real world environment: a café. Guests are able to sign up for newsletter (advertisement) and also can interact with the menu of the café and leave remarks (guest book) [CNH06].

*Virtual Reality* (VR) environments and the related fields of *Augmented Reality* and *Immersive Scenarios* are still fields of great interest for both the computer graphics as well as the human-computer interaction community. Also users out of various disciplines are interested in possible application areas of VR, AR and Immersive Scenarios.

Cruz-Neira et al. did lay the fundamental basis for *Cave Automatic Virtual Environment* (CAVE) display systems [CNSD+92], [CNSD93]. The user is surrounded by walls on which images are projected. The *Viewer-Centered Perspective* simulates the view from user perspective. This is achieved by constantly tracking the position of the user and adjusting the projected images.

Raffin and Soares [RS06] rate the hardware advances (Graphic Processing Units, GPU) as the milestones for tracking and visualizing high quality content in VR environments.

Schaeffer and Goudeseune introduce the *Syzygy* software library, providing users with the necessary tools for implementing for PC clusters and driving VR applications on them [SG03].

## 2.3 LCD-based Tiled Display Systems

LCD-based tiled display systems have several advantages over projector-based systems. The most obvious advantages are: LCD-tiled display systems are

(a) more cost-efficient (considering the *pixel per $* formula).

(b) capable of a higher resolution (pixel-per-inch).

(c) more convenient to calibrate (geometric calibration/color calibration).

(d) not high-maintenance (no limited life cycle of projector lamps).

(e) not prone to the shadow problem like front-projector tiled display walls.

(f) space-efficient (no space for projection needed).

(g) combining high-resolution and large screen real estate.

(h) enabling user collaboration and social interaction in front of a large screen.

(i) not that vulnerable to environment lighting conditions.

In the following the advantages will be described in detail.

(a) A 30" LCD with a native resolution of 2560 x 1600 pixels is more cost-efficient than a similar XHD projector, capable of equal resolution.

(b) When defining resolution by ppi (pixel-per-inch, pixel density), LCDs have an advantage since the resolution is fixed to a certain screen size. In theory one can increase the pixel density of projectors, but that is not very applicable, since projection space has to be shortened dramatically, therefore limiting interaction possibilities with front-projection systems.

(c) A basic geometric calibration can be achieved by carefully adjusting the LCDs, mounted in a proper rack (Figure: 2.5), by using a water level. Colour calibration can be achieved easily, but that has not been subject of this thesis.

(d) LCDs are not high-maintenance. Projector lamps only have a limited life cycle and if one projector lamp breaks, one should change all, since there will be color & brightness differences. This leads to increased maintenance as well as follow up costs of projector-based approaches.

(e) The space in front of the LCD-based tiled wall systems can be used for interaction and collaboration, one major contribution of large display environments in general. There are no shadow issues like one has with front-projection walls, seriously limiting the user interaction in front of the display wall.

(f) The space required to set up a LCD-based tiled wall is manageable and therefore even suitable for smaller work environments with limited space.

(g) LCD-based tiled walls combine high-resolution and large screen real estate. The setup at University of Kaiserslautern (3 x 3 30") (Figure: 2.1) has a combined screen surface of almost 3 $m^2$ and a combined resolution of 7680 x 4800 pixels.

(h) Users can exploit the open space in front of LCD-based tiled display walls to facilitate human-computer interaction as well as human-human interaction with collaborators/colleagues. Content can be discussed immediately. Physical navigation and spatial memory can be utilized.

(i) When using projectors the light conditions of the demo-room have to be taken into consideration. When using LCD-based systems this fact is not as crucial as with projector-based systems.

The LCD-based tiled display wall at the University of Kaiserslautern (Computer Science and HCI Group), Germany (Figure: 2.1) consists of 5 render nodes (using off-the-shelf, commercial hardware) driving a 3 x 3 display wall configuration. The 30" LCDs used for this setup, Dell UltraSharp 3007WFP, feature a screen resolution of 2560 x 1600 pixels. This leads to a combined resolution of 7680 x 4800 pixels and a screen real estate of almost 3 $m^2$, enabling users to collaborate in front of the tiled wall configuration.

A 5 x 10 display configuration is set up at the University of California, Irvine (Figure: 2.2). 25 Apple Power Mac G5 nodes drive the 50 30" Apple Cinema LCDs (2560 x

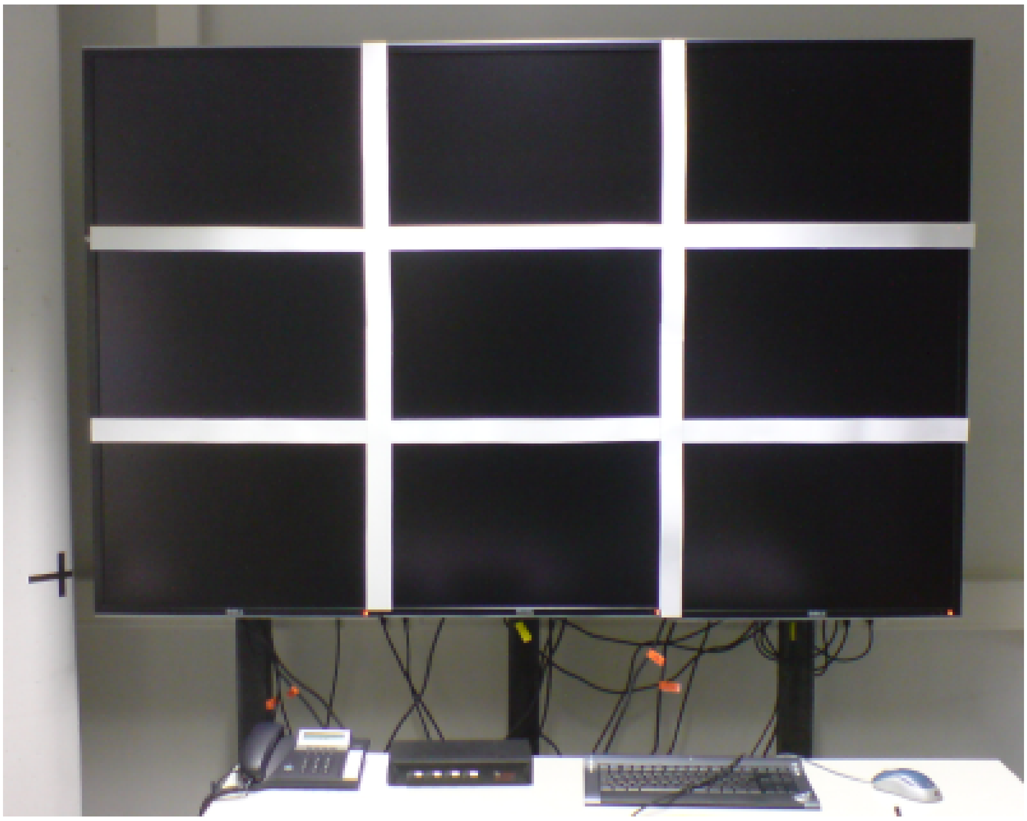


Figure 2.1: A 3 x 3 LCD-based tiled wall system, set up with non-reflective cardboard for the Tiled++ approach, University of Kaiserslautern, Computer Graphics and HCI Group, Germany.

1600 pixels). This leads to a combined screen resolution of 25600 x 8000 pixels and a screen surface of about 18 $m^2$. Larger groups of users can collaborate in front of this display configuration.

With tiled display configurations collaborative work environments are provided. Multiple users can access information, multiple users can interact with the display, large datasets can be visualized on screen without the need of permanent pan & zoom operations.

With tiled display environments both the visualization and human-computer interaction communities have a scalable tool-set to facilitate developments in both areas. It is now up to them to exploit the emerging possibilities to create collaborative


Figure 2.2: HIPerWall, a 200 mega-pixel, 5 x 50 LCD tiled wall setup, UC Irvine, CA, USA.

work environments. One of the biggest challenges is finding areas of application, not reducing tiled display walls to static information kiosks.

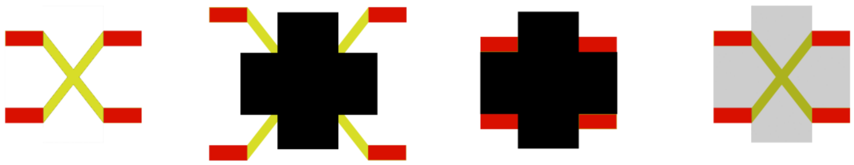
Commercial manufacturers of tiled display environments, like Planar [4], also promote tiled displays as architectural accessories (*Planar Mosaic*) and for digital signage purposes in public space.

### 2.3.1 Semantic Loss - "Visualization behind bars"

When creating tiled display environments, multiple devices (be it projectors or LCDs) are joined together to create one large, high-resolution screen.

Today's LCDs feature a *display frame*, not only the display area is visible to the user, in fact the display surface is "framed". When setting up a LCD-based tiled display wall, the user has to deal with the fact that the large display surface is punctuated with the frames/bezels of the LCDs, resulting in an effect similar to a *French window/porte-fenêtre*, causing a *semantic gap*.

[4] http://www.planar.com/



(a) Original image (b) Offset (c) Overlay (d) Tiled++

Figure 2.3: Schematic representation of the the two traditional approaches on how to display content on a LCD based tiled wall. The Tiled++ approach is offering benefits in avoiding both deformation and loss of information [ETO+10]. (a) is showing the original image, (b) is using the Offset approach, leading to image deformation in the bezel crossing area, (c) is showing the Overlay approach with missing image content and (d) is showing the Tiled++ approach, adding the missing image information by projection.

There are basically two traditional approaches in how to deal with visualization content and the monitor crossings. Figure 2.3 provides a schematic overview of these two approaches: Figure 2.3(a) provides the original image, Figure 2.3(b) shows the *Offset* approach leading to a deformation of the original image (stretched, since the image is continued on the neighbouring screen), In Figure 2.3(c) the *Overlay* approach is shown, leading to missing image information, since the bezel area is treated as display area and therefore occludes the image, *"displayed"* beneath it. Figure 2.3(d) shows the *Tiled++* approach, introduced in the next subsection.

The schematic overview clearly demonstrates the issues using the traditional approaches regarding visualization on LCD-based tiled wall systems. The user has to deal with *semantic loss*, by both the *Offset* and the *Overlay* approach, resulting in a distorted user perception or even a loss of image information.

The bezel problem is specific to LCD-based tiled walls, but also projector-based tiled walls have issues regarding the allocation of a real seamless display surface (due to color & brightness issues).

Software solutions to address the problem of *semantic loss*, e.g. the work of Mackinley and Heer [MH04], only provide a workaround, not really addressing the bottom of the problem.

Ni et al. [NSS+06] state that the number one research challenge, among others, is the implementation of truly seamless tiled display environments.

### 2.3.2 The Tiled++ approach

Unlike with projector-based tiled wall systems, suffering from a non-seamless image caused by color and brightness differences, LCD-based tiled wall environments suffer from a hardware issue. In consequence of the construction of recent LCDs, the bezels are a necessity because they host the control electronics to drive the LCD panel. Contrary to the problems projector-based approaches face, a solution to the bezel problem can not be a software-based solution. With LCD-based approaches a software solution only can reduce the *symptoms*, not provide cure for the *actual disease*: the bezel effect, caused by the display frames.

With the *Tiled++* approach ( [ETOH08], [ETO+10]) the bezel problem itself is addressed. The basic idea behind Tiled++ is to utilize the bezel area as additional screen area.

Tiled++ uses the *Overlay* approach as a general mode to display information on the 3 x 3 prototype. The high-resolution content is displayed on the LCDs, therefore omitting the image information occluded by the display frames. With regular LCD-based tiled walls the image information will be missing, resulting in loss of information and therefore in a semantic gap. With Tiled++ the usually omitted information is projected onto the bezel area. Since the Dell UltraSharp LCDs feature black frames, the bezel area carefully was prepared with non-reflective cardboard to allow for projection. In order the eliminate interference of projection with the LCD surfaces, black projection was used on the LCD areas. Figure 2.4 provides a schematic representation of the 3 x 3 Tiled++ prototype.

Tiled ++ features two display areas:

(a) high-resolution area (LCD screens).

(b) low-resolution area (bezel area).

In summary Tiled++ can be described as an *inverted* Focus & Context approach.

#### 2.3.2.1 The Tiled++ approach - Creating a high-resolution Focus & Context Display

By utilizing the bezel area and providing the missing image information to the user's eye as context information, a focus & context like display is created. The user has access to high-resolution display areas (the LCD screens) where one can perceive detailed **focus information**. The bezel areas, with low resolution content projected onto them, provide **context information**, thus minimizing the semantic gap. Unlike to traditional focus & context environments, the focus area of Tiled++ is quite large and occupies the majority of the display configuration.

Since the context information is projected in a significant lower resolution onto the bezel area, the difference of focus & context areas are obvious. One can not speak of a *true* seamless display and therefore one has to be more precise in defining seamlessness.

Tiled++ directly addresses the hardware problem and therefore offers a solution for the problem of semantic gaps, resulting from the non-display areas, hiding or distorting image information. With Tiled++ a seamless LCD-based tiled wall is presented, seamless in the sense of *semantic seamless.* Tiled++ combines an innovative approach, providing both hardware and software aspects to address the most pressing issue with LCD-based tiled wall environments: the bezel problem.

#### 2.3.2.2 Calibration of the Tiled++ System

Basic alignment of the 3 x 3 prototype is achieved by a special rack (Figure 2.5), allowing the alignment of the LCDs. The basic alignment is crucial in order to receive an *as-seamless-as-possible* image, and also to provide for an optimal (planar) mounting platform for the cardboard, used as projection space for the Tiled++ approach.

**System Calibration using the calibration tool**

The calibration procedure of a Tiled++ system, in general consists of two steps:

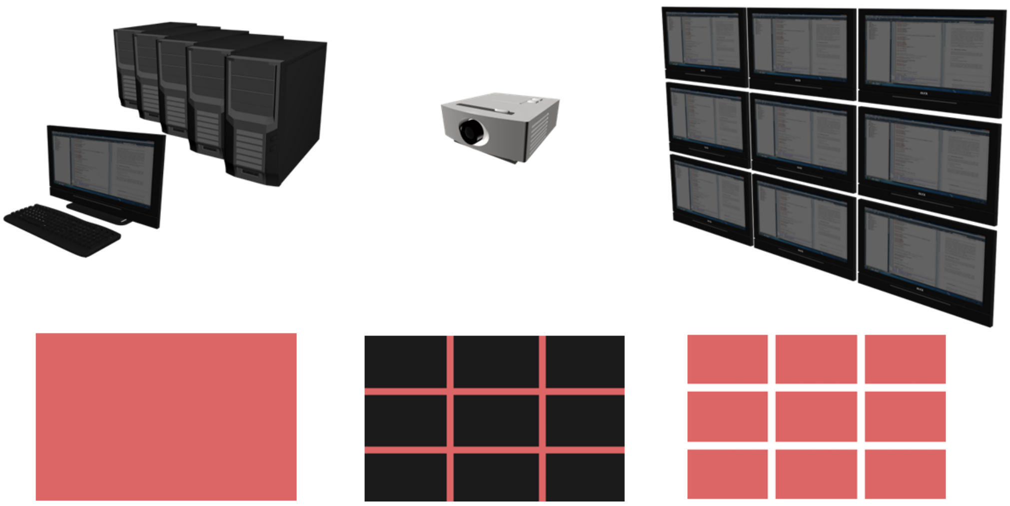


Figure 2.4: Schematic representation of the Tiled++ cluster. The render nodes drive the displays, the projector and render & distribute the content [Ole12].

1. *Determining the basic geometry of the tiled display.* This information is stored in a *configuration file*, containing measured size, location, as well as bezel size of each screen. The configuration file later is parsed to the *render framework*.

2. *Basic projector calibration.* The projection has to cover the total tiled display screen area and has to get aligned with it, seamlessly.

The underlying *render library* of Tiled++ has been designed to be highly configurable as well as flexible, making the Tiled++ approach scalable and user friendly. One aspect of scalability is the configuration file, providing basic information about the LC panel setup to the render framework. The determined values tell the library the position of each LC screen, size of screen, as well as the bezel size. Based on this information the system knows where a projection is needed and where not. Since the projection is of significant lower resolution, projecting onto the LCDs would interfere with their higher resolution. Therefore only the bezel area is used as projection canvas, the LC panels are cut-out (blacked out, black projection on LC screens).

Besides the advantage of being able to deal with inaccuracies of the rack, this approach also offers real scalability in creating arbitrary display environments. The

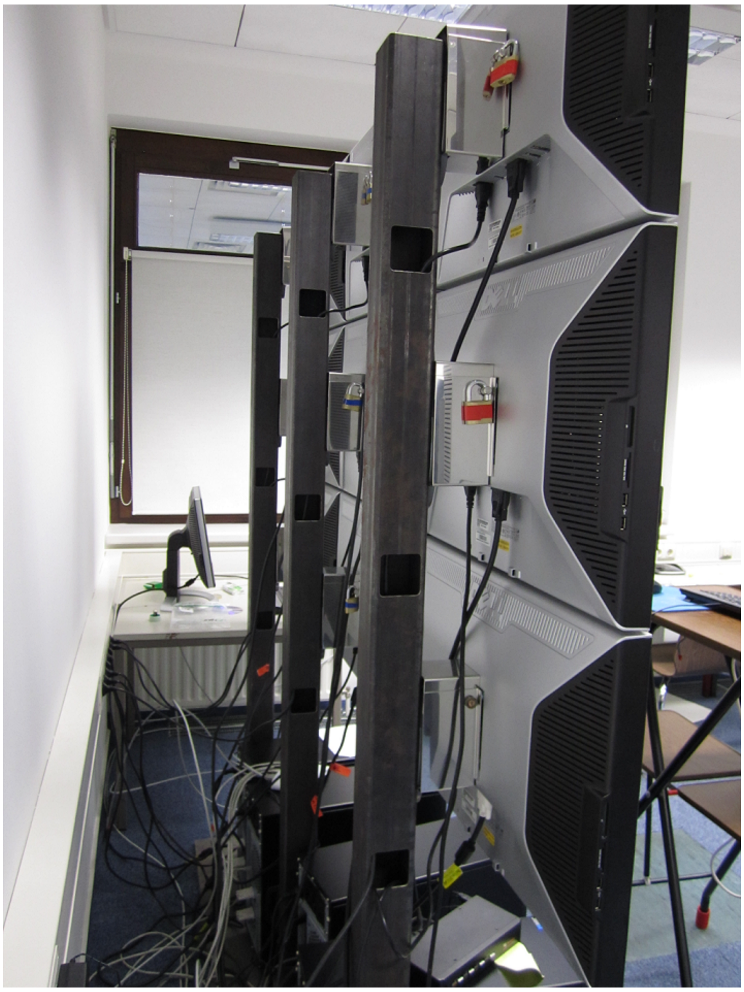


Figure 2.5: Mounting rack of a LCD tiled display wall, University of Kaiserslautern, Computer Graphics and HCI Group, Germany.

users are not bound to traditional rectangular tiled wall systems, similar to the work of Baudisch et al. [BGS01].

The major issues for projector alignment within the Tiled++ environment are geometric alignment, luminance alignment and color alignment. Basically every technique known from projector-based tiled display environments alignment can be applied to Tiled++. Focussing on the feasibility of the Tiled++ approach, calibration has been restricted to *geometric alignment*, only. By applying additional calibration techniques the overall quality of the Tiled++ approach can be improved.

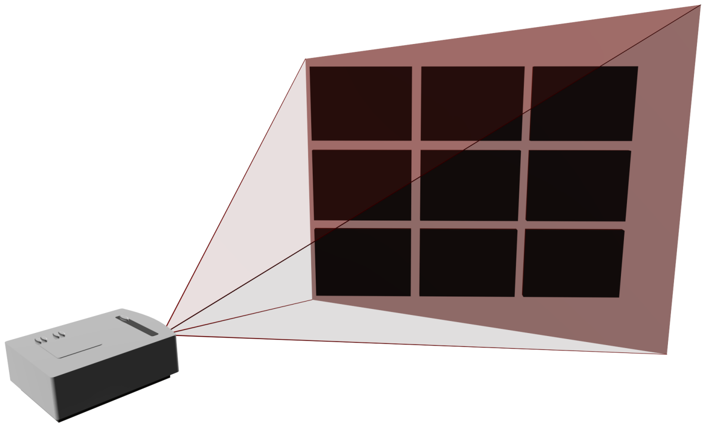


Figure 2.6: The *keystone* effect, a trapezoidal distortion of the projected image, caused by the angled projection [Ole12].

To provide physical interaction possibilities in front of the screens, without compromising the projected context information, the projector is set up on the side of the tiled wall, thus projecting in an angle. By placing projectors in non-perpendicular positions to the tiled display wall, the projected image is trapezoidally distorted (*keystone effect*) (compare Figure 2.6). To compensate the keystone effect a homography is computed in order to eliminate the unwanted distortion caused by the angled projection, since the built-in keystone correction of modern projectors is not sufficient to achieve satisfying results. This keystone calibration is achieved by using the calibration tool, allowing semi-automatic calibration of the Tiled++ system.

A homography is a mapping that preserves the collinearity of points and the concurrence of lines in two-dimensional projection space.

It is defined by four two dimensional point pair correspondences:

$\{L_i \leftrightarrow R_i\}_i$

The homography is computed by determination of the coefficients

$\{h_{ij}\}_{i,j}$

of a $3 \times 3$ homography matrix $H$.

It follows:

$R_i = H \cdot L_i$.

A homography maps points of one quadrilateral to corresponding points of another quadrilateral, therefore providing the basic principle for keystone correction.

With the determination of correspondences, by using a regular web camera and solving the system of linear equations, the entries of a homography matrix $H$ are obtained. $H$ is multiplied with OpenGL's projection matrix in order to distort the projector image to get proper geometric alignment, eliminating the unwanted keystone effect.

#### Driving Arbitrary Display Setups - AnyScreen

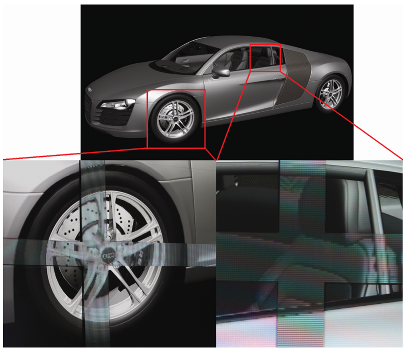
*AnyScreen* [DTS+09] is a platform-independent, robust and versatile rendering framework, capable of driving arbitrary display setups. The AnyScreen framework derived from the Tiled++ framework, extending the functionality in order to increase scalability and fields of application.

One example of such an arbitrary display environment using the AnyScreen framework is introduced by Steffen et al. [SEDD09]. With *five*, a 2D + 3D projector approach is presented. By adding a designated 2D projection area in a stereoscopic projector wall environment (PowerWall) the problem of textual visualization and bad readability in 3D environments is addressed.

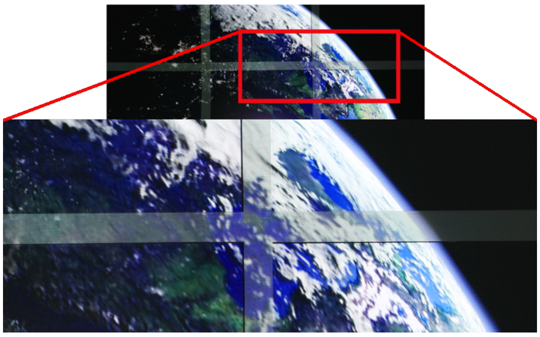
### 2.3.2.3 Tiled++ - Quality

Tiled++ is offering good image quality. The difference between focus area and context area is obvious but there is no semantic loss. Perception-wise users benefit from the Tiled++ approach.

Figure 2.6 is providing two examples of the quality of Tiled++. In Figure 2.7(a) the rim and interior of the Audi R8 are enhanced with context information, providing a complete picture without semantic loss. In example 2 (Figure 2.7(b)) a Virtual Globe, featuring the NASA *Blue Marble* textures, is shown. The user perceives the content without a semantic gap, although the bezel area still can be distinguished easily.



(a) Tiled++ result example 1



(b) Tiled++ result example 2

Figure 2.7: Actual examples of the image quality of the Tiled++ approach. Clearly visible is the lower resolution on the non-reflective cardboard area [Ole12]. (a) Tiled++ is offering the image information concealed under the bezel area of the LCDs. (b) A virtual globe with the NASA blue marble high-resolution texture is shown. The user can notice brightness differences, since the projector used in the prototype could not match the brightness of the LCDs.

Where there is sunlight, there are also shadows: the problems of the Tiled++ approach can be identified, as follows:

(a) protruded projection area.

(b) low resolution.

(c) color and brightness calibration.

The protruded projection area is caused by the LCD frames being not on a plane with the display panels itself. Depending on the viewpoint, the users notice that the projection area is protruding the screen, causing a small gap.

The issues of low resolution projection onto the bezels can be addressed by using a projector capable of higher resolution or using multiple projectors, a feature supported by the *AnyScreen* rendering framework.

As a proof-of-concept prototype, the focus on calibrating Tiled++ has been on a basic geometric calibration. Both brightness (luminance) and color calibration have not been conducted but can be addressed in future, to further enhance the user experience, when working with Tiled++.

An evaluation of the Tiled++ approach, comparing and analysing its effect on user perception, is found in Chapter 3.3 of this dissertation.

## 2.4 Going public - Large Public Displays

Large public displays are well known for signage and advertisement purposes in urban & public environments. However, user interaction is not intended for these display configurations or at least interaction is very limited. On the other hand, traditional information terminals, which can be found at airports or train stations, allow for user interaction. But they are not suited to accommodate multiple users and interaction can be described as mediocre (keyboard and trackball interaction), basically providing a desktop computer replacement in public spaces to suit the very basic needs of browsing the internet or writing emails.

Traditional bulletin boards, also known as black boards, offer public wall space to attach *pen & paper* notes, e.g. for selling goods, renting apartments, searching for runaway cats/dogs (Figure 2.8). Information is shared with the public in a very efficient way. The major shortcoming of these bulletin boards is the lack of organization. They can become messy and amorphous very fast, the displayed content usually has no date stamp and therefore no *expiration date*. The information provided by traditional bulletin boards often is outdated.

In the following two public display environments are introduced, addressing the shortcomings of existing public displays as well as traditional bulletin boards.

### 2.4.1 Digital Interactive Pinboards

An alternative approach to share multimedia files on large public displays is the **D**igital **I**nteractive **P**inboard (DIP) architecture [TCO$^+$10]. Users can share multimedia content by using their own mobile phone for interaction with public digital pinboards.

The basic idea behind the DIP approach originates from traditional bulletin boards, which also are set up in well-frequented places, so called *hotspots* (Figure 2.8).

Figure 2.8: A typical bulletin board, located in a hot spot (canteen area), University of Kaiserslautern, Germany.

On these traditional bulletin boards users can post messages and notes, for example lost & found messages, sale advertisements, public announcements. The messages posted are visible to the public and therefore no specific user group can be addressed. Traditionally these boards have been set up at well-frequented locations, like supermarkets, building entrances (town hall, for official announcements), in university lobbies, ideally they are set up in natural bottle-necks to slow down the potential audience. Setting up the bulletin boards in such hotspot environments has the advantage that potential users float by and can stop and browse through the information, without the need to plan this action in advance.

Traditional information bulletin boards offer a great way to exchange information. However all information posted on these boards is public and content can be disorganized and chaotic. In most cases the recipient also does not know if the information still is valid or outdated.

In short, information is provided to the general audience (no potential target audience). The information is presented to the recipients in an indirect way. They are usually in a state of reduced activity and are under influence of minimal *auditive & visual distractions*.

To overcome these shortcomings, a digital & improved version of traditional bulletin boards, DIP, is introduced.

DIP follows the principle of traditional bulletin and provides a fixed information sharing point, located at a hotspot.

Unlike other systems the DIP approach does not serve as a *passive* public display, for advertisement & signage purposes, it supports advanced mobile phone interaction possibilities.

With the DIP approach, the fact that most information today is *digitally available*, the exchange of information/content (image files, audio files, video, documents etc.) is optimized for camera-enabled mobile phone interaction.

With DIP, users or user groups can filter the information on the public display, they can also restrict the access, limiting the audience, making DIP a feasible approach, even when sharing more sensitive information.

In addition DIPs encourage users to interact with each other, since the hotspot location also can be regarded as a meeting point and therefore a strong social component is present. For interacting with a DIP, the users have to be on-site, making physical presence a necessity. With DIPs, traditional billboards are modernized, keeping the good features like social interaction and improving not so good features (*messy boards*) by providing a digital, thus organized pinboard, making interaction more convenient.

#### 2.4.1.1 Digital Interactive Pinboard Functionality

It is an assumption that the DIP users are part of a social group and each member has a mobile phone device, capable for interaction (camera equipped).

The individual user/mobile phones is registered to the digital pinboard database.

Pinboard access for the client (the user's personal mobile phone) is granted, by using a stable Internet connection (wireless), which is provided to the users in the proximity of the public display.

To select items displayed on the public scree, two-dimensional *visual tags/barcodes* serve as mode of interaction between the clients and the display. For user friendliness and duplicability *Quick Response* (QR) codes are used to label items and therefore serve as unique identifiers.

To interact with an item of interest, the user uses the camera-enabled mobile phone to scan the QR code, sending a *request* to the server and *triggering* the desired interaction.

DIP supports the following file types:

(a) Video files (.avi).

(b) Audio files (.mp3 & .wav).

(c) Image files (.png & .jpg).

(d) Documents (.pdf & .txt).

The DIP server GUI (compare Figure 4.8(a)) is divided into two areas, each representing a *privacy level* for each shared file, added to & shared by the DIP system. This approach allows for a clear privacy functionality by providing immediate access to *public* content, while limiting access to *private* content.

The DIP approach emphasizes the strong social component of sharing digital content and interacting with a public digital bulletin board.

#### 2.4.1.2 Implementation Details

DIPs are implemented as *client-server* applications. The user's interaction device, the mobile phone acts as a client that communicates with the server (DIP). Ideally the server is running on the same computer which is driving the public display. The system architecture is illustrated in Figure 2.9.

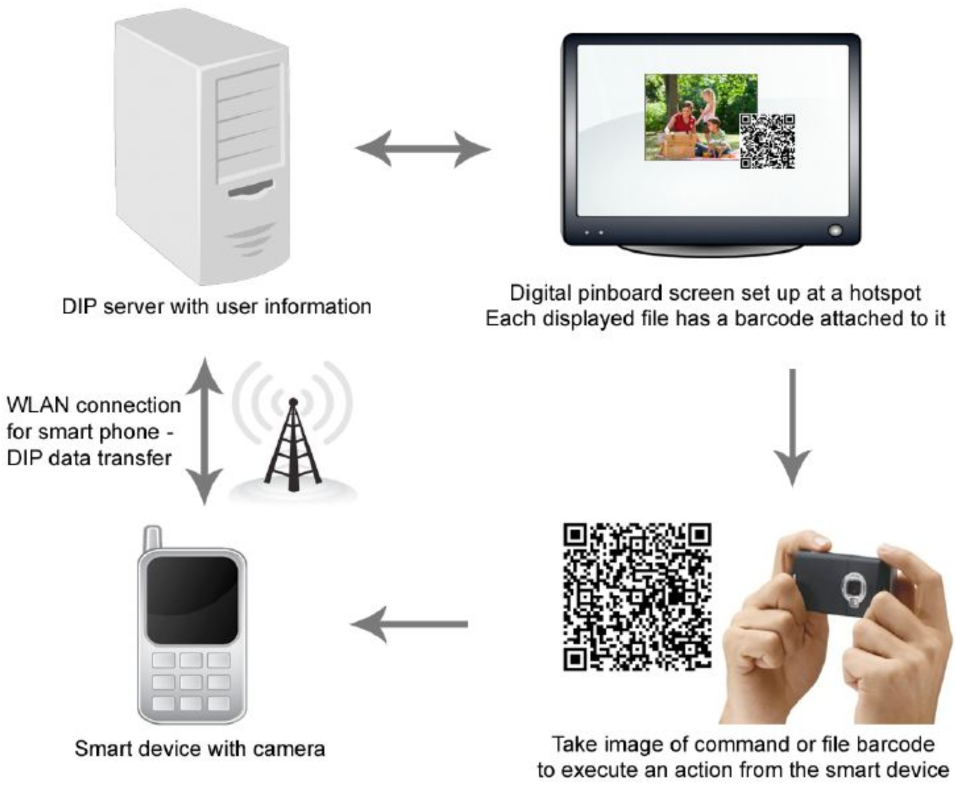



Figure 2.9: System architecture of the DIP approach (Digital Interactive Pinboard) [TCO+10].

For data transfers, the files transferred are encapsulated XML messages, thus providing *platform independence*. By doing so a variety of mobile phones are supported by the DIP architecture.

The DIP prototype features a *.NET-based C#* implementation for supporting *Windows Mobile* clients and a *Objective-C* implementation for *Apple iOS* clients.

The server side was implemented using the *.NET framework*, GUI design was realized by using *Microsoft Silverlight*, the board content (files, messages, QR code) is stored and managed by a *Microsoft Access* database. The QR codes are generated for each file in the DIP system, making it possible to identify every file, allowing for indexing in the database. The QR codes are generated by an open source library on the DIP server and decoded at client. Each QR code serves as an unique primary database key.

The display used for the prototype setup, as well as the scenarios, features a 46” Sony BRAVIA HD display. Since scalability has been a major concern during the concept & design phase of the DIP approach, additional displays can be added, increasing screen real estate and allowing for a larger group of users. If projectors are used to set up a DIP system, then back-projection is recommended, in order to avoid shadowing, caused by users interacting in front of the display/screen area. Furthermore the DIP server supports adjustment of both icon and QR code size, as well as re-positioning the items displayed, according to DIP screen size and resolution, making it a scalable solution for arbitrary display environments.

### 2.4.2 Digital Interactive Public Pinboards for Disaster and Crisis Management

The dramatic events of 2010 and 2011 have shown the vulnerability of mankind is, when it comes to natural disasters. Providing adequate and effective counter measures and help are most crucial issues in the aftermath of disasters, be it natural or man-made disasters. After the devastating disasters, like the earthquakes of *Port-au-Prince*, Haiti (2010), *Christchurch*, New Zealand (2011) and *Tohoku*, Japan (2011), ultimately triggering a tsunami which caused a nuclear disaster, it has become obvious that international relief and emergency response has to be improved, in order to minimize casualties and to provide adequate relief measures as fast as possible.

After the earthquake in Haiti (2010), arriving responders had to deal with outdated map material. Roads were blocked by debris and the map material available did not show the actual situation, because it already had been outdated. Finding alternate routes has been time consuming, in a situation where seconds matter. Current map material (including satellite imagery) was available, but was not been distributed to relief personnel.

The lack of both information flow and coordination problems also caused confusions for arriving first responders after the earthquake & tsunami disaster in Japan,

2011. Foreign first responders arrived and were basically left alone, with no information and no disaster management coordinating foreign aid personnel. Foreign relief personnel had to leave empty handed, shortly after arrival.

These two examples give insight how crucial it is to

(a) provide up-to-date information

(b) verify the validity of information

(c) ensure a constant flow of information

(d) make sure that the information is distributed to those in need

(e) to properly organize and coordinate the emergency measures

(f) provide the logistical support

(g) provide a basic infrastructure

(h) manage personnel.

With the **D**igital **I**nteractive **P**ublic **P**inboard (DIPP) [OCM+12] a versatile approach is introduced, addressing the existing issues, pointed out beforehand. DIPPs are an efficient and reliable way to share information, manage help personnel (e.g. coordinate search & rescue teams), provide a basic overview of logistics (e.g. medical supplies, water, accommodation) in times of emergencies and disasters.

Derived from traditional bulletin boards, providing the option to post messages (lost & found, for sale, for rent etc.) and public announcements on a board, which then are available to the broad public. These boards have been set up in well-frequented places, in order to achieve a maximum outreach. The problems of traditional billboards already have been described in Section 2.4.1. The Digital Interactive Public Pinboard (DIPP) approach, as an *enhanced* and *mature* version of the Digital Interactive Pinboard (DIP, compare Section 2.4.1), not only addressing these problems, but also providing an infrastructure to suit the crucial requirements, demanded of a disaster and crisis management system.

To ensure outreach of arriving foreign first responders, suitable hotspot locations to set up DIPP systems are airport locations, for example. Upon arrival, DIPPs can provide up-to-date situation reports, current news, basic information (what, where, when, who). Users can register and therefore being able to contribute to the system and benefit from a enhanced functionality (e.g. search for colleagues, obtain contact informations). Setting up public information systems in hotspots also has the advantage that a fixed location is provided, thus creating a *contact point*. These contact points not only serve for information distribution and sharing, they also serve as points of social interaction between the users.

Besides the more or less basic requirements, ensuring basic functionality of disaster and crisis management systems, another crucial requirement for such systems is *comprehensibility* and *ease of use*. It has to be taken into consideration, that users from various backgrounds and with diverse fields of expertise need to be able to

1. access and understand the provided information
2. being able to interact with the DIPP.

Visual representation of the information has to be suitable and comprehensible, the method of interaction has to be convenient and simple, without the need for a long training period or studying a complex user guide.

Mobile human-computer interaction (mobile HCI) enables users to interact with the DIPP architecture in a convenient and user friendly way. Smart phones have become widely available everyday devices, offering multiple interaction and communication modalities, like WIFI network, Bluetooth, GPS, cameras, and touch screens, which can be utilized for mobile HCI.

One lesson learned after the Tohoku earthquake and the aftermath, resulting in a nuclear meltdown, has been the fact, that Internet has been available, when both land-line as well as mobile phone networks have been compromised. In order to overcome the shortcomings of past disaster and crisis experiences and to ensure an adequate flow of information, the DIPP approach features an architecture to provide both stability and up-to-date information. With mobile device interaction a maximum flexibility in both communication and interaction modalities is achieved.

#### 2.4.2.1 Conceptional Design

My conceptional design for the development and the implementation of a first prototype of the DIPP disaster and crisis management system are introduced in detail.

**General considerations**

A disaster is a damaging event, which can't be effectively solved at a local or at a supra-regional scale, within an acceptable time frame. Relief endeavours at a larger scale are necessary in order to resolve the disaster event, generally speaking, international aid intervention is necessary [fBuK10].

Keeping this definition of *disaster* in mind, the main focus of DIPP is on external, international first responders, approaching on-site with only rudimentary information and therefore in need of up-to-date information and guidance, but not limited to. Since local scale personnel already is retained by measures to address the disastrous event, a DIPP system can provide information and guidance to arriving aid personnel, thus unburden local personnel.

International relief is not limited to large organizations like *Red Cross*, *Federal Agency for Technical Relief* (THW), *US Agency for International Development* (USAID), also smaller organizations as well as individuals provide relief. With the DIPP architecture a centralized information platform is provided, making it possible to collect and share recent information, therefore making information available, especially for smaller organizations and individuals which are not connected to the networks of large organizations.

**Why choose Public Displays?**

Traditional pinboards, well known from universities as well as supermarkets, provide information, based on pen & paper notes and therefore often are outdated. With DIPP, digital & recent information is made accessible for arriving relief personnel, e.g. at an airport, at a hotspot location. The DIPP not only serves as an *information access point*, it also serves as a *meeting or contact point*, enabling social interaction among users. The DIPP approach features a large public display, enabling multiple users to interact with one display. The large display allows, unlike to traditional information terminals, that multiple users can access information; at the same place, at the same time. On the DIPP public screen relevant information is visualized in an easy-to-perceive way, in order to allow fast and reliable comprehension among the diverse users, without the need of a long training period or going through a manual. Key function of the DIPP architecture is to collect and distribute information, to enable users to access information, making coordination possible. Effectiveness and efficiency of relief workers are crucial criteria in order to minimize losses and to provide adequate relief as fast as possible.

**What is the purpose?**

The DIPP architecture allocates a locally centralized information system, set up at hotspot locations to provide

(a) coordination

(b) collect information

(c) share & distribute information

(d) a contact point for social interaction.

DIPP allows user interaction with mobile devices over a WIFI network. The system is based on a client-server architecture, granting access over a local WIFI network. The basic system structure is provided by the server side, also driving the public displays. The users communicate with their own mobile devices (serving as the clients) with the server (e.g. user registration, exchanging information, uploading pictures, downloading map material, and a search function).

**What are the essential features needed?**

As mission critical functionality DIPP features:

*First responder management*:

The users are able to register with the DIPP system. By creating user profiles (e.g. name, profession, contact information, GPS camp coordinates) users are able to browse for other help personnel, e.g. by profession in order to collaborate or exchange specific information. By doing so, cooperation is facilitated and specific help is found easier.

*Deployment of up-to-date information*:

Users are able to access up-to-date information (e.g. recent map material, recent satellite imagery, contact information, GPS coordinates of accommodation possibilities & camps) at the hotspot locations, where the DIPP systems are set up. A centralized system, like DIPP, in addition mitigates the risks of unverified and invalid information.

*Logistics*:

Basic necessities like accommodation, water supply, food supply, medicine, the coordination of tasks, e.g. search & rescue are organized and coordinated.

*Communication*:

A basic communication infrastructure is ensured by DIPP. WIFI networks are stable, as the incidents in the past, like the Japan earthquake in 2011, did prove. Contact data can be shared among the registered DIPP users, in order to make communication possible. The hotspot locations also serve as contact points.

*Hazards*:

Relief workers are on-site to provide help. This does not mean that they have to put themselves in harm's way and carelessly risk their lives. By visualizing known geo-related hazards, e.g. aftershocks, leaking oil pipelines, fires, chemical & biological & radiation hazards, relief workers are warned of potential risks and therefore see what safety precautions are necessary when entering a specific zone.

**What features should be included?**

In addition to the *core* features of DIPP (focussing on foreign relief personnel) there are other functionalities extending the functionality of DIPP to the local disaster relief forces and the population of the disaster area.

*Missing people*:

Publish missing people and providing basic information (e.g. name, address, picture, last known position) in order to initiate a large pool of users and therefore boost the chance of finding a missing person. The missing people database is updated if a change of status (e.g. located, deceased, whereabouts) is made. Updating information in real time is a big plus, unlike to traditional pen & paper or printed-out notes on traditional bulletin boards.

*Mission specific tasks*:

The ability to organize open tasks, e.g. search for missing people, gather information of badly damaged areas, restore infrastructure, and to assign people to these specific tasks, based on their field of expertise. An electrical engineer can assign to the task of restoring electricity in a certain area. The *open* task of *restore electricity in area XYZ* then is marked as *taken*, in order to ensure that there is no overlap in task assignment (task status: open, pending/taken by, resolved, need additional help). Furthermore information about the assigned group or individual is stored (e.g. competence level, reputation).

*Visual representation of information*:

One key function of DIPP is the visualization of information on public screens. The visual representation not only include recent statistics, but also predictions about the supply situation, so that scarcity and bottlenecks of supplied goods are avoided.

#### 2.4.2.2 The DIPP Prototype

The DIPP system prototype is based on the NASA World Wind Java SDK 1. DIPP combines an emergency management system with public screens and mobile interaction.

In July 2011 version 1.2 of the NASA WWJ SDK [5] framework was released, as the first stable release. The major advantage of the framework is it's flexibility and scalability, making implementation of extensions and modifications easy and therefore allowing functionality tailored to the specific needs of the user community.

[5] http://worldwind.arc.nasa.gov/java/

Data is loaded from a local buffer memory and a 3D view is available, derived from a peculiar elevation model, similar to the Google Earth [6] application. Contrary to Google Earth, World Wind offers the major advantage of being platform independent, the only requirements to the Operating System (OS) are: support OpenGL functionality. For an application like DIPP this is a crucial factor, because it can be set up quite easily and therefore greatly enlarges the number of potential users. In addition the framework is published under the Nasa Open Source Agreement (NOSA), making it a cost effective tool for the non-commercial research community.

### Implementing the server

With accessibility as being one of the key features of the DIPP prototype the visualization of events is important. The events should be recognized by the users without the need to browse through a manual, cross-check a legend or go through a list of keys. The symbols used in the DIPP system to represent events are designed correspondent to the standards of the U.S. Department of Defense (DoD), in order to ensure a high recognition value.

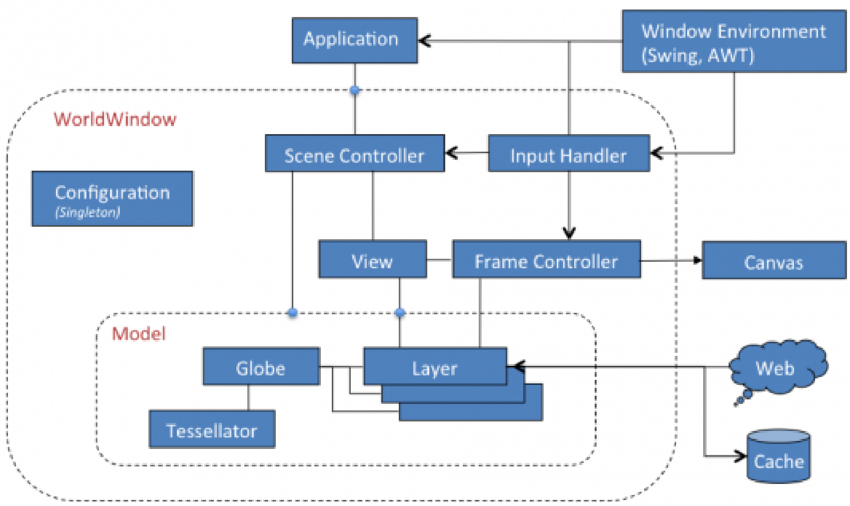



Figure 2.10: The World Wind Java framework overview.

[6]http://www.google.com/intl/en/earth/index.html

As basis of the DIPP application map material from the *Open-Street Map* (OSM) project [7] is used. Designated servers provide the map material which can be edited to suit the user's needs. Additionally the map material offered by the OSM project is the only one which is freely available and of high precision. Earthquake data is provided by the *United States Geological Survey* (USGS), using GeoRSS [8], providing recent data.

A brief overview of the framework is provided by Figure 2.10 [9]. A planet and an elevation model are representing the globe model. The elevation model, generated by a *tesselator*, as well as the layer structure are projected onto the globe, representing grid and vector data. During navigation (in general: user interaction) the represented objects keep their position. The model is compiled out of the data which is displaying the layer structure. An *InputHandler* and the user trigger the user's view on the model (view). The model istelf is drawn by the *SceneController*, furthermore determining when it is actually drawn, by combining view and model. During the runtime in the *AWT/Swing* environment the object *WorldWindow* is created and integrated in the Canvas.

In order to meet the *mission critical* requirements of the DIPP prototype, as set out in detail in the previous subsubsection (*Concept*), new classes and packages had to be implemented. Figure 2.11 introduces the 5 standard classes (highlighted in blue) and provides detailed insight in one of the prototype's core features (the accommodation feature).

As a first step the *DisasterManagement* main application is created, followed by the *DisasterManagement SettingsPanel*. User interaction with data (e.g. adjusting data, enter data, switch layers on/off) is done in the SettingsPanel. By calling the method *load-FromXMLFile* (String xmlFile) an accommodation vector is created by the *DisasterManegementSettingsPanel*. Based on the elements of this vector, the information bar is loaded by an *AccommodationPanel* (also loaded by the accommodation vector). Simultaneously objects of the accommodation vector and the method *addAccommodation* (Accommodation a) are parsed to the *Accommodation*

[7] http://www.osmfoundation.org
[8] http://www.georss.org
[9] http://goworldwind.org

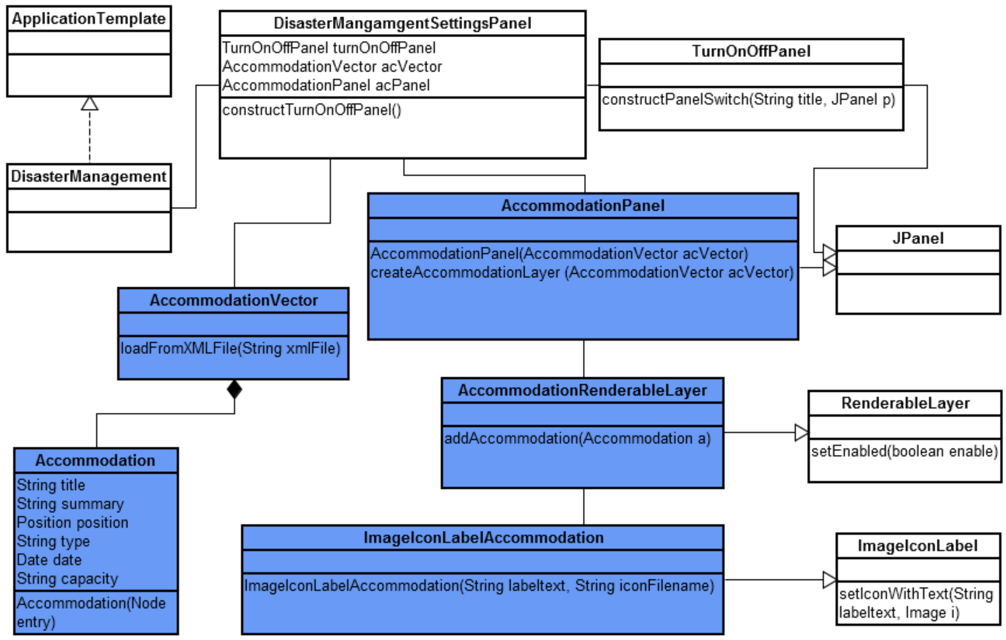



Figure 2.11: Prototype implementation. The accommodation class [OCM+12].

*RenderableLayer*. This action creates an *ImageIconLabelAccommodation* which then is added to the *AccommodationRenderableLayer*. On the map all elements added to the *AccommodationRenderableLayer* are displayed. Images are loaded from the subfolder file structure img/*.png, whereas the file name has to correspond to the attribute of the XML-file. As a last step a *TurnOnOffPanel* is loaded by the *DisasterManagementSettingsPanel*, enabling users to turn on and off the different layers. With the method *setEnabled* (boolean enable) the *RenderableLayer* is activated or deactivated by a simple check-box.

## 2.5 Virtual Reality Environments

CAVEs (**C**ave **A**utomatic **V**irtual **E**nvironment) have been around since 20 years. The first CAVE has been developed and implemented at the UCI (University of

Illinois at Chicago, U.S.A.) [10], at the Electronic Visualization Laboratory (EVL) [11] in 1992 [CNSD+92], [CNSD93].

A CAVE basically is a "room"; its walls consisting of rear-projection screens. By a carefully aligned array of mirrors, projectors are able to project imagery onto the screens, surrounding the user (or users), as well as onto the floor of the CAVE. The user's shutter glasses are synchronized with the projectors in order to provide correct 3D imagery. The user (usually only one user) is tracked (both glasses as well as the interaction device) using electro-magnetic sensors (e.g. *Flock of Birds* [12]). The user information (position of head, position of interaction device) is captured by the tracking system and used to compute/generate the view, as well as for interaction purposes.

Figure 2.12: A **C**ave **A**utomatic **V**irtual **E**nvironment (CAVE), FBK, University of Kaiserslautern, Germany.

[10] http://www.uic.edu/
[11] http://www.evl.uic.edu/
[12] http://www.ascension-tech.com/realtime/rtflockofbirds.php

Among the original *CAVELib* API (**A**pplication **P**rogramming **Interface**, developed by EVL, there are numerous other frameworks able to drive CAVE systems (e.g. Syzygy (Software) [SG03], VR Juggler (API) [BJH+01]).

In order to use a common platform for software development for CAVE systems, the VRUI (**V**irtual **R**eality **U**ser **I**nterface) [13] middle ware is used to facilitate collaboration and to provide *exchange-ability*, *manageability* and *flexibility*.

While being capable of multi-user interaction and collaboration in the CAVE, a shortcoming becomes obvious: there is always a *Master user*, being tracked and responsible for interaction, the other users of the CAVE can be considered as *audience*, or to use consistent terminology, *Slave users*. Since the calculations of the projected imagery are based on the captured information of the *Master user*, all other collaborators have to live with a *not to their position adjusted image/visualization*. Depending on their position inside the CAVE in relation to the *Master user* the effects on user perception can be minor or major.

Nevertheless, CAVEs can provide a solid basis for intuitive and natural visualization approaches, especially for native 3D datasaets, like LIDAR (**LI**ght **D**etection **A**nd **R**anging) point cloud data. VR environments also can be used for virtual design approaches, e.g. in mechanical engineering or even virtual walkthroughs in the field of architecture. The immersion factor of users is higher, compared to conventional 2D screen environments.

CAVE systems enhance user perception, especially when working with native 3D data. Users can navigate to a point of interest, physically. Thus VR interaction is quite close to regular interaction with real world objects.

Despite all advantages and visualization possibilities, CAVE systems remain niche products. They are a very specialized form of visualization and presentation environments. Especially in regard to the initial cost price, maintenance efforts (set up, calibration and follow-up costs) and space requirements (e.g. separate room with proper lighting or the technical capabilities, to ensure these conditions).

[13] http://idav.ucdavis.edu/ okreylos/ResDev/Vrui/index.html

## 2.6 Summary

Since display environments are used to convey visualizations to users, they also do provide the work environment in terms of how users can collaborate or interact with the displayed content.

Traditional single display environments (the *classic desktop* computer work space) suffer from both limited screen real estate and as well as moderate resolution, hampering interaction of multiple users in front of one screen. Not only in terms of collaboration with colleagues or in a research team the work flow is chocked off, also in terms of working with large data sets the interaction mechanics demand permanent user attention and active user interaction. Large datasets most likely will not fit the limited screen space provided by a single display. Users therefore have to choose between a general overview, making details that small that they can't be apprehended in the right way, or accessing detailed information by zooming into the dataset, at the cost of losing context information.

Permanent panning & zooming operations are not desirable, during exploration of large datasets, especially if having a smooth work flow, in terms of usability aspects, in mind.

Tiled display environments can make a contribution in addressing the beforehand mentioned shortcomings, by providing both large screen real estate and high-resolution. The positive effects on user tasks, in certain application areas, already have been pointed out, e.g. in the work of Ball and North. User performance is increased by enabling physical navigation as well as spatial memory, leading to improved usability.

In areas, where team work and working with large datasets are essential tasks, scalable tiled display wall environments are a feasible solution to create large high-resolution display environments, suitable for collaborative work.

The Tiled++ approach addressed one of the most urgent research issues in the field of LCD-based tiled display environments, by providing a nearly seamless large display environment.

| Display type | Size | Resolution | Scalability | Mobility | Cost |
|---|---|---|---|---|---|
| Tiled Display | varies | very high | very good | in theory | varies |
| Public Display | moderate | moderate | OK | yes | low |
| CAVE (VR) | large | moderate | no | no | very high |

Table 2.1: A brief Comparison of the versatility of observed display types [Ole12].

Public displays make a contribution to specific task areas. In the application field of disaster management they can be useful as interactive information points, being able to distribute more recent information than traditional billboards. Users can fall back to info points, accessing information and also meet with other people, in order to exchange information. Besides the allocating of an information infrastructure, in addition a basis for social interaction is created. Furthermore a DIPP architecture is simple and robust, both important criteria for crisis and emergency scenarios.

Virtual Reality environments such as CAVEs or other 3D capable approaches (PowerWall) offer new ways of visualizing information and also interacting with it. CAVEs are suitable as collaborative work environments, although the majority of CAVEs allow only for single user interaction, making the other collaborators *spectators*.

Generally speaking, the display type enables new ways of visualization metaphors, new ways of interaction, collaborative work, enables the utilization of physical navigation, peripheral vision, spatial memory. Table 2.1 provides a basic overview about the potential, which the observed display environments offer.

Displays can support users by fulfilling the more and more complex task they have to face today. In today's visualization environments display technology plays a crucial role. Display technologies can be regarded as one part of the puzzle to create user-centered applications, increasing the positive user experience in terms of usability.

A legitimate question is, if a 200 mega-pixel display can be utilized in an useful manner and where human perception again has to deal with problems like *too much information* and the necessity of filtering *unwanted or unnecessary information*, therefore counteracting the intended purpose to enhance usability.

# Chapter 3

# EVALUATIONS AND USER STUDIES IN THE FIELD OF HUMAN-COMPUTER INTERACTION

## 3.1 Introduction

New developments in the area of computer science have the aspirations to provide support to its users. To enhance and improve existing approaches, be it hardware or software.

Evaluation approaches have been a common part of product and material development in the fields of engineering, natural sciences, construction, just to name a few. For decades user studies and evaluations have been an industry standard to measure the customer/user satisfaction, before releasing a new product to the market. Computer science also creates products, demanding interaction of the users. With terms like *usability* (ISO standard 9241), as sketched in Figure 3.1, user studies and evaluation techniques have become an essential part of computer science, especially in the field of Human-Computer Interaction (HCI).

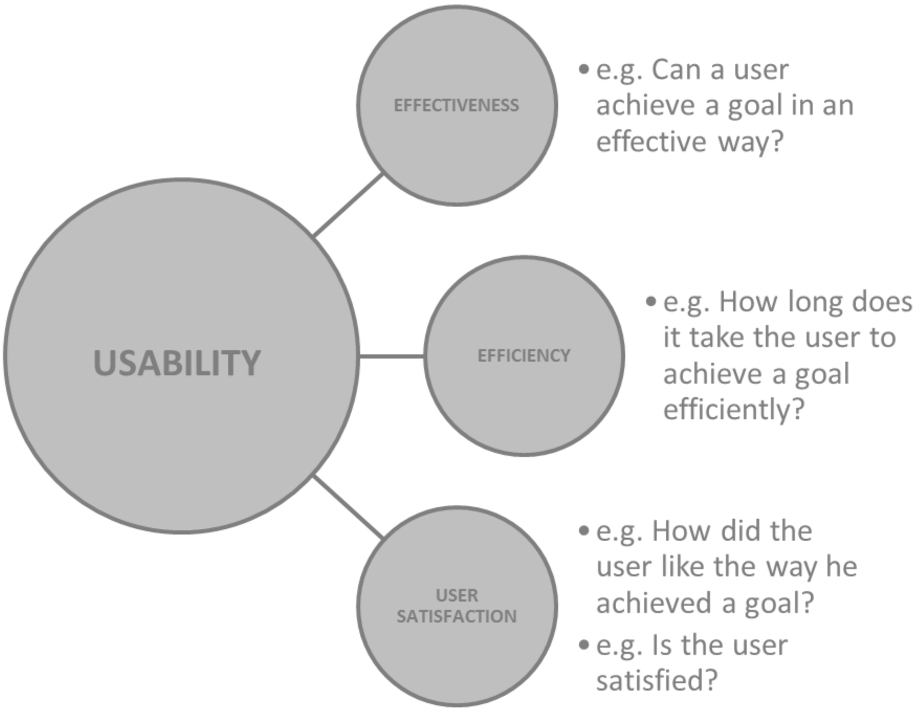



Figure 3.1: ISO standard 9241. Usability and the usability categories [Ole12].

Carefully conducted user studies can be a decisive factor, if an approach (e.g. interaction technique, new interaction device) really can withstand in everyday use. Usability guidelines as well as project management tools help to ensure quality standards.

Both evaluations and user studies can be conducted during the whole life cycle of a development process (Figure 3.2), ensuring to meet the needs of users (following the waterfall model of Dix et al. [DFAB03]). Testing the product is an ongoing process to ensure quality standards, functionality and at the same time to minimize invested time, if certain things do not work out as intended. Although conducting user studies and evaluating a product (hard- or software) is a time consuming process, during all stages of the design cycle, the efforts can pay out, since, in a worse case scenario, that the evaluation reveals negative results, only one stage of the cycle is lost, not a whole product. The term *lifelong learning* can be conveyed to the *User-Centered*

*Design Cycle*. The continuous process of evaluations and improvements ensure a product, meeting the requirements and standard.

In the following two evaluation approaches are described, one evaluation providing validation of a new concept, in order to get insight if it proofs useful and provides benefits to users, compared to existing approaches.

The second evaluation presented is not testing a new product, on the contrary it evolves in a very early stage (in the concept phase), in order to gain additional information on how to improve the product by early participation of potential users.

This chapter concludes with a rather new interaction device, the *Emotiv EPOC neuroheadset* (at least new in its consumer market version), which is not only feasible as a traditional interaction device, furthermore it also can be utilized for evaluation purposes in order to gain additional information on the user's experiences during evaluation tasks.

## 3.2 State of the Art

Tiled display approaches have been evaluated and their benefits for users have been pointed out in numerous publications. In the following a short overview about important related evaluation approaches is given.

Ball et al. evaluate the benefits of different display setups when navigating maps by comparing user performance using a single display setup, a 2 x 2 tiled display setup and a 3 x 3 tiled display setup [BVC+05]. The results showed that the 9 display setup improved user performance significantly. Based upon their work a similar approach is used by increasing both display size and display resolution [SBY+06]. In addition to planar tiled display walls a curved tiled display configuration is evaluated.

Ni et al. [NBC06] empirically clarify the relation of screen size and user performance. The findings of the authors state that both screen size as well as resolution can improve user performance in tasks.

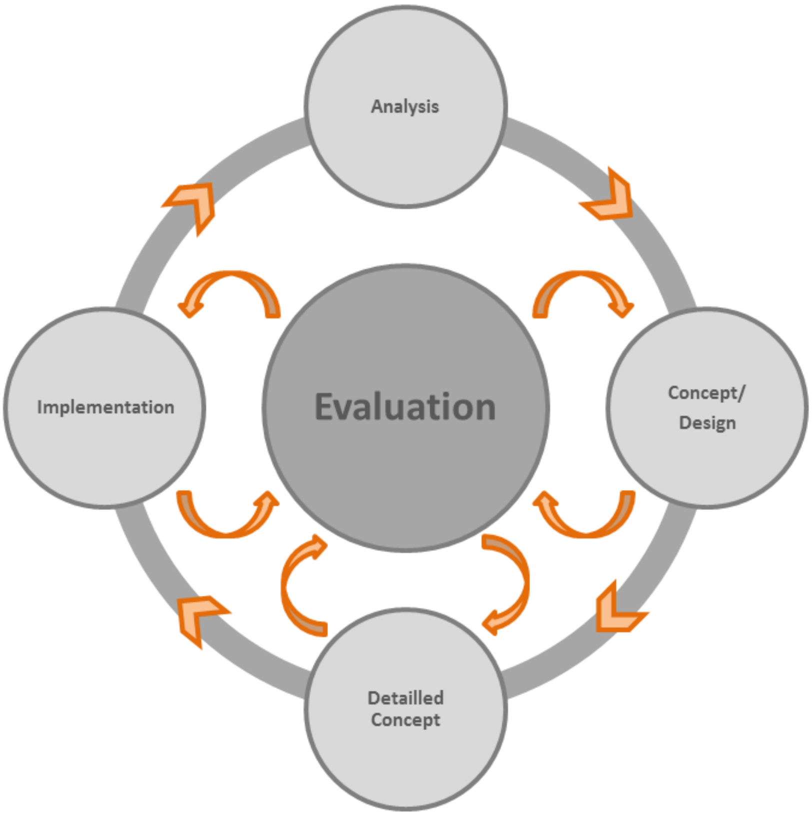



Figure 3.2: The User-Centered Design Cycle, following the waterfall model of Dix et al. [DFAB03].

In the work of Ebara et al. [EKK08], [ES09a] remote tele-immersive collaboration approaches using tiled display environments are evaluated. As a result eye-to-eye contact, via high-resolution video, is enabled and enhancing remote collaboration.

A more general approach in the field of evaluating usability is provided by Frokjaer and Hornbaek [FH08]. They introduce metaphors of human thinking (MOT), in order to achieve more versatility in usability evaluation techniques. The authors argue, that most techniques used are only suited for very specific cases and lack transferability.

The preceding work of Hornbaek and Frokjaer [HF02b], [HF03], [HF04] also deal with the implementation of metaphors of human thinking for usability evaluation purposes (user interface evaluation).

In [FHH00] Frokjaer et al. illuminate the correlation of effectiveness, efficiency and satisfaction, the aspects which comprise usability. It is argued that each aspect has to be considered as an independent aspect of usability.

An overview of current practices in the field of usability evaluations is provided by Hornbaek [Hor06].

Learnability, one aspect of usability is not defined by metrics argue Grossman et al. [GFA09]. A classification system, based on the findings of previously used methodology, is created.

With the increasing availability of Electroencephalography (EEG) devices tailored for the consumer market, new interaction modalities for user interaction can be implemented. Although being used as interaction device for handicapped people, as proposed in the work of Leeb et al. [LFMP+07], with decreasing prices products like the Emotiv EPOC wireless headset [1] become available for a broader audience. In the work of Campbell et al. the EPOC wireless EEG headset is used for interacting with a mobile phone.

Randy and Adamovich [RA10] introduce the EPOC headset for controlling an external robotic arm. Touch Bionics [2] already is offering Brain Computer Interface (BCI) controlled prosthetic devices.

Horlings et al. [HDR08] use EEG signals to measure and detect emotion. 5 classes in the 2 emotional dimensions are measured. The results to detect and classify the emotion states correctly have been positive.

Mikhail et al. [MEAEK+10] also detect emotions by using a feature detection system for noisy EEG data in order to isolate and detect emotion.

[1] http://www.emotiv.com/
[2] http://www.touchbionics.com/

## 3.3 Evaluating the Tiled ++ approach

The *bezel problem* is one of the major problems users have to cope with, when setting up LCD-based tiled display environments. The bezel crossings either hide image information or deform the picture.

With the Tiled++ approach users can counteract the shortcomings of traditional approaches. In order to evaluate the Tiled++ approach, an extensive user study has been conducted [ETO+10].

### 3.3.1 Goal of the evaluation and Experimental Design

After introducing a solution for creating a seamless LCD-based tiled display wall, the new approach, Tiled++, is compared to existing approaches, in particular the *Overlay* approach and the *Offset* approach, to gain insight if value is added by using the bezel areas of the tiled display setup as projection space for *context* information.

Since the focus was on the bezel areas user interaction has been limited to traditional keyboard & mouse interaction devices. Thus providing well known interaction devices to avoid falsification of test results due to new interaction devices and interaction metaphors. Not the interaction device has been in focus of this evaluation, the Tiled++ approach has been evaluated in order to get insight on both user performance and perception experiences.

The evaluation has been conducted in the *Demo Room* of the Computer Graphics and HCI Group, University of Kaiserslautern. All tests have been implemented on the 3 x 3 prototype LCD-based tiled wall system.

#### Population of evaluation

20 test candidates volunteered to participate in the evaluation study, 16 male and 4 female study participants.

The majority of participants has been recruited from the department of computer science, in order to ensure considerable knowledge and experience with computers.

6 of the test candidates have been undergraduate students, making the remaining test candidates graduate students.

The majority of participants claimed never or only rarely utilizing multi-monitor systems. 3 candidates use multi-monitor systems during work, on a regular basis.

Average age of test candidates has been 29.3 years (ranging from 21 to 49 years).

### Experimental Design

The experimental design consists out of two task areas: interaction tasks (*Pong*, *HotWire*) and perception tasks (*Poggendorff* Illusion, Animation sequence).

The dynamic interaction tasks require user interaction across all screens, including the display crossings. By using both traditional approaches on how to deal with the display crossings (overlay, offset) and the Tiled++ approach, differences in user performance (effectiveness, error rate; efficiency, time) can be revealed and measured.

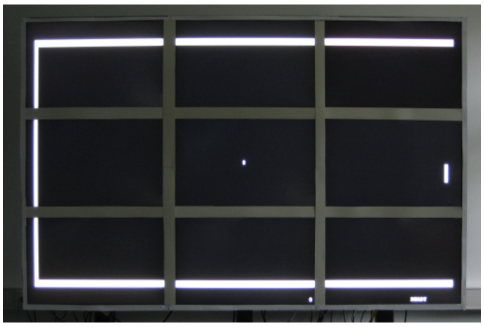
The static perception tasks are used to test user perception. The user feedback has been collected in questionnaires, providing statements in regard to their *user experience* and *user satisfaction*.

### Interaction task 01: Back to the early 70s: The *Pong* game

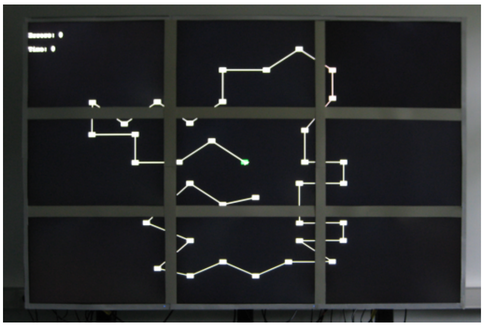
As one of the interaction tasks the arcade game classic *Pong* is re-implemented as a single player version. The user interaction is limited to moving one virtual line, representing a tennis racket, up and down and returning a virtual tennis ball, bouncing off a virtual wall, see Figure 3.3(a). The number of returns is documented.

The *Pong* game is intuitive and easy to play, since interaction is limited on vertical movement of the tennis racket, making it also playable for people not familiar with computer games.

With *Pong*, a dynamic task is presented to the test candidates, in order to gain insight on how they perform using the three bezel-handling methods (Tiled++, offset, overlay). Since the ball is moving quite fast, the traditional methods of



(a) Pong. A remake of the classic arcade video game in order to test user interaction.



(b) HotWire. A game of skill. The task for the test candidates is to follow the line (wire).

Figure 3.3: Experimental design to evaluate user interaction & performance while performing two tasks using three different rendering approaches, namely Tiled++, offset and overlay [ETO+10]. (a) The *Pong* game task, a challenging user task. (b) The *HotWire* task, demanding a steady hand.

handling bezel areas can be quite a challenge for users: the ball can disappear under a bezel segment (overlay) or rapidly change direction (offset).

The test candidates played three stages (10 balls/attempts each), comparing the three different approaches to deal with displaying content of LCD-based tiled display walls: *offset* approach, *overlay* approach, and the *Tiled++* approach.

In this experiment design the *independent variable* is the one expressed by the levels (Tiled++, overlay, offset), whereas the *dependant variable* is represented by the measured number of total returns per level.

#### Interaction task 02: Keep a steady hand! The *HotWire* game

The second navigation task also is derived by a game. The *HotWire* game is a *game of skill*. The player has a looped wire, which he has to manoeuvre along a bend, curved wire, without making contact. If the player fails and the looped wire is touching the curved wire, the electric circuit is closed and a light bulb or ring is signalling and the the player has to restart.

The implementation of the *HotWire* game for the evaluation follows this concept. The test candidates have to follow arbitrary lines and if the line is left, an error is logged and the user has to return to the last way-point (”checkpoint”), he passed safely (compare Figure 3.3(b)). Unlike the traditional game of skill, in the evaluation setup players do not have to start all over again, if making an error. After a short time penalty users are allowed to restart from the last safely passed checkpoint. Both the time to complete the task, as well as location and number of errors are logged.

The test candidates also play three rounds, one round for each approach, the layout of the ”wire” changes, each time, in order to avoid a learning effect.

The *independent variable* of the experiment design is expressed by the three levels (Tiled++, overlay, offset).

The time the test candidates need to complete the task, is the *dependent variable*.

Each test candidate performing the *HotWire* task is measured, regarding task completion time and in addition the error rate is recorded and where the errors occur. In an ideal case a significant number of errors will happen in the bezel crossing areas, where the user has to move the cursor from one display to one of the neighbouring ones, thus revealing navigation issues with the *offset* and *overlay* approaches.

The layout of the ”wire” has been implemented following the design principles:

(a) For each run of the game a different layout is used in order to prevent learning & training effects.

(b) The layout is of equal length and difficulty, in order to achieve results which are comparable. By deriving each layout from a *template* by applying *length-preserving geometric transformations* (mirroring, rotation).

(c) By the almost circular layout of the *HotWire* route, handedness (left hand, right hand) advantages were ruled out.

(d) The ratio of vertical and horizontal movements is uniform, in order to avoid potential advantages by performing certain movements.

(e) In order to generate regular layouts, the directional changes after checkpoints are restricted to predefined angles, avoiding acute angles.

(f) By definition of maximal segment lengths, fast walk-throughs ("taking a short-cut" and skipping checkpoints) by uncontrolled mouse movements, are prevented.

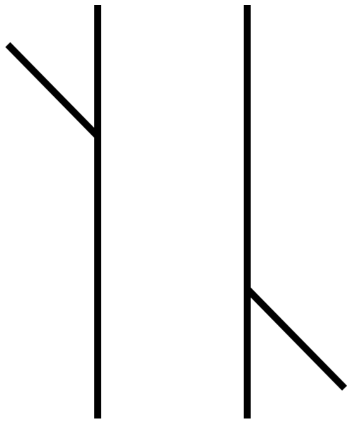


Figure 3.4: The Poggendorff Illusion (J. C. Poggendorff, 1860).

With the *HotWire* game a test to reveal possible differences when navigating from display to display, using the different approaches, has been conducted. The findings then are examined and used to determine if the bezels have a serious effect on the user's performance and which approach improves user performance.

**Perception task 01: The *Poggendorff* Illusion**

The *Poggendorff Illusion* is a well known optical illusion 3.4, described by the German physicist Johann Christian Poggendorff in 1860. This optical illusion is the basis of the first static tasks the probands did experience during the evaluation. Two parallel vertical lines separate a diagonal line, making the collinear oblique lines appear to be disjointed (compare 3.4). Figure 3.5 describes the problem in detail: the human brain perceives the diagonals disjointed, they appear offset. It is hard for users to determine which of the two right diagonal lines are matching the left part of the diagonal. This phenomena can be conveyed to LCD-based tiled display setups. There the bezels disjoint the image information, from display to display, even when using the *overlay* approach. With the *offset* approach the image appears deformed, anyway.

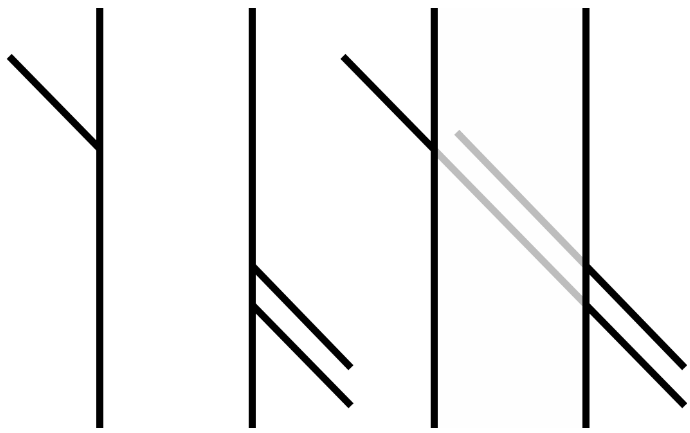


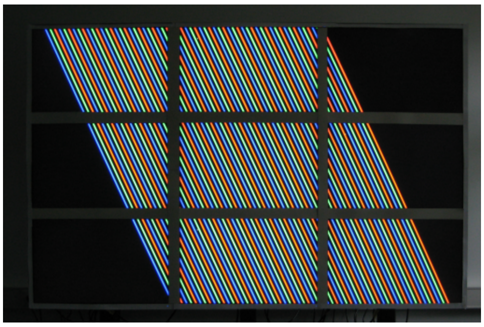
Figure 3.5: Poggendorff Illusion: The problem of connecting the diagonal line. The human brain fails to fill the gap, a problem appearing at monitor crossing areas [Ole12].

The major problem of connecting content spanning across multiple displays (e.g. graph visualization, mind maps, circuit boards) is present with regular approaches (*overlay* & *offset*). Connecting lines is a hard task, when passing from one screen to the neighbouring screen.

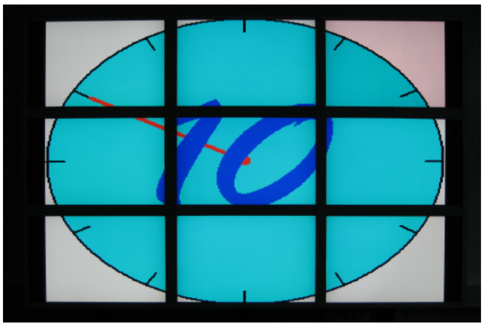
The task given to the test candidates was to connect the lines using both the *overlay* and the *offset* approach. There was no time measurement involved in this part of the evaluation. The test candidates were asked to investigate the Poggendorff Illusion by themselves and provide us with feedback, regarding their own findings. These findings later were covered by the questionnaire.

At the first stage of this experiment the diagonal lines were displayed as white lines on black background. To provide some support to the users, in aiding them connecting the diagonals across the display seams, color could be added to the lines, as seen in Figure 3.6(a). Users could use the colors to verify if they had been able to connect the right (corresponding) diagonals.

The *offset* approach naturally does not have the effects arising with the *overlay* approach: the diagonals continue on the neighbouring display, offset, but no image information is lost. However, the distortions are directly related to the *offset* approach, not to the *Poggendorff* phenomena coming along with the *overlay* approach, where image information is *lost* under the bezel areas.



(a) The Poggendorff Illusion.




(b) The second perception task is a simple animation displayed on the 3 x 3 tiled display wall.

Figure 3.6: Experimental design to evaluate user *perception* while presented three different rendering approaches, namely Tiled++, offset and overlay [ETO+10]. (a) The *Poggendorff* illusion, a optical illusion to test the test candidates ability to connect lines in bezel crossing areas. (b) The short *animation* sequence, a ticking clock.

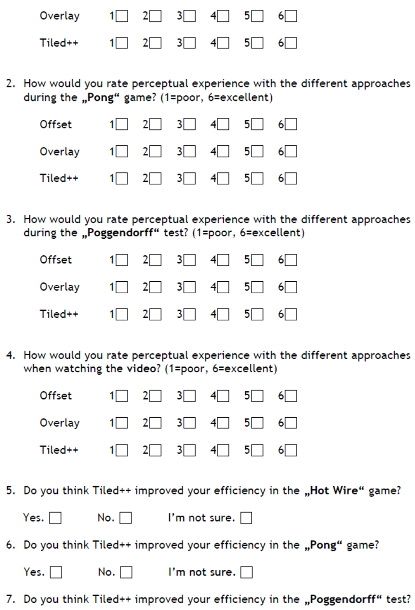
Nevertheless, the three approaches, namely *offset*, *overlay* and *Tiled++* were presented to the users, to let them experience the pros and cons of each approach.

### Perception task 02: Animation

Referring to most common uses of tiled display walls, in particular signage and advertisement purposes (e.g. sport stadiums, digital advertisement panels) a simple animation sequence, a *ticking Clock*, see Figure 3.6(b), was presented to the test candidates, by using the *offset*, *overlay* and *Tiled++* approach.

After perceiving the animation sequence using the different visualization methods, the test candidates were asked to rate their experience in the questionnaire.

Their findings and remarks regarding image distortion, coming along with the *offset* approach, have been compared to the *overlay* approach, hiding parts of the displayed content under the bezel areas, and the *Tiled++* approach, providing parts (bezel areas) of the displayed image information in lower resolution and without advanced color and brightness adjustments.



Overlay 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Tiled++ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

2. How would you rate perceptual experience with the different approaches during the **„Pong“** game? (1=poor, 6=excellent)

Offset 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Overlay 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Tiled++ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

3. How would you rate perceptual experience with the different approaches during the **„Poggendorff“** test? (1=poor, 6=excellent)

Offset 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Overlay 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Tiled++ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

4. How would you rate perceptual experience with the different approaches when watching the **video**? (1=poor, 6=excellent)

Offset 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Overlay 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

Tiled++ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐

5. Do you think Tiled++ improved your efficiency in the **„Hot Wire“** game?

Yes. ☐ No. ☐ I'm not sure. ☐

6. Do you think Tiled++ improved your efficiency in the **„Pong“** game?

Yes. ☐ No. ☐ I'm not sure. ☐

7. Do you think Tiled++ improved your efficiency in the **„Poggendorff“** test?

Figure 3.7: Excerpt of the questionnaire which the test candidates completed after the tasks [Ole12].

### The questionnaire

After completion of the four tasks (*Pong*, *HotWire*, *Poggendorff*, and *Clock*) the test candidates have answered a questionnaire (Figure 3.7) consisting of 16 questions. Out of the 16 questions, 7 have been directly related to the user experiments. In addition, general impressions and open questions should provide more in-depth information, especially in regard to further enhancements of the *Tiled++* approach. For classification purposes the questionnaire concluded with general information about the test candidates (e.g. gender, age group). Test candidate selection has not been representative, it has been a selection of users.

An example of questions, including:

(a) How would you rate perceptual experience with the different approaches when watching the *Clock* animation? (1=poor, 6=excellent)

(b) Do you think Tiled++ improved your efficiency in the *HotWire* game?

(c) Do you think that users of LCD-based tiled display walls can benefit from the Tiled++ approach? Please give a short justification of your answer.

| Approach | Mean # of returns | Standard deviation |
|---|---|---|
| Offset | 10.1 | 6.99 |
| Overlay | 13.55 | 9.48 |
| Tiled++ | 12.05 | 12.24 |

Table 3.1: Averages and standard deviations of returns for the *Pong* task [ETO+10].

### 3.3.2 Results of the Evaluation

The results of the evaluation indicate the overall contribution of the Tiled++ approach in regard to usability. Depending on the task, the contribution of the Tiled++ approach is significant.

#### Analysis of variance (ANOVA)

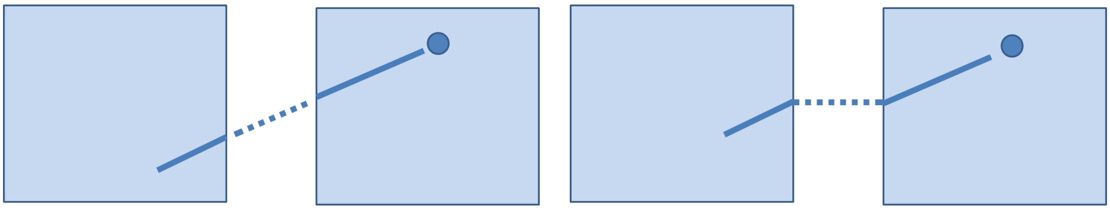
Based on the measured data, obtained from the two interaction tasks *Pong* and *HotWire*, an one-way **An**alysis **o**f **Va**riance (ANOVA) study has been conducted, in order to verify if the measured evaluation task results (*Pong* & *HotWire*, the interaction tasks) are significant (in combination with the Tukey HSD post-hoc test).

#### Lessons learned from the interaction tasks

When analysing the data conducted during the interaction task *Pong* no differences among means have been noticed. None of the three implemented methods out-performed one or the other. As seen in Table 3.1 no method is significantly better. The expectations that the Tiled++ approach provides additional benefits and advantages for users performing the *Pong* task, could not be backed up by this evaluation. The assumption had been, that the users gain benefits from the additional information provided by the projection onto the bezel areas, thereby eliminating the shortcomings of the other approaches (provide image information and no distortion) in order to estimate the trajectory of the ball.

With the overlay approach the ball is hidden under the bezel areas and the users have to estimate trajectory (compare 3.8(a).

The offset approach is accountable for a *jump* of the ball: the ball ”leaves” on one end of the display and ”enters” the other display ”offset” (in fact it is not ”offset” because the bezel area simply is ignored and the offset is due to the physical gap between LC display surfaces, compare Figure 3.8(b)).



(a) Trajectory using the overlay approach. (b) Trajectory using the offset approach.

Figure 3.8: Trajectory of the ball using *overlay* and *offset* approach [Ole12]. (a) The trajectory is sketched by dashed lines. (b) The trajectory is offset. Users have to compensate for the monitor crossings.

The result can be interpreted the following way:

By having a dynamic environment, with rapid movements, the intensity of the bezel problem, interfering and therefore influencing user performance in a negative way, decreases. Users seem to focus on the overall image, not on a specific part of the displayed content. Fast changing environments seem to divert attention from the bezel crossings to the overall picture. As seen in the schematic sketch (Figures 3.8(a) & 3.8(b)) the deviation of trajectory is not that vast.

Performance-wise the Tiled++ approach could not come out on top of the two competing methods, but perception-wise the majority of users favoured the Tiled++ approach.

In Figure 3.9 the findings from the questionnaire are represented. In the questionnaire the test candidates rated (ranging from 1 = poor to 6 = excellent) their experience with the *Pong* task, differentiating the visualization methods. User preference is in favour of the Tiled++ approach, although there was no measured advantage. Contrary to the fields of effectiveness and efficiency, the field of user satisfaction still is fraught with uncertainty, in terms of subjectivity.

When performing the *HotWire* task both time and also errors have been captured. In Table 3.2 mean time and errors as well as standard deviations are summarized.

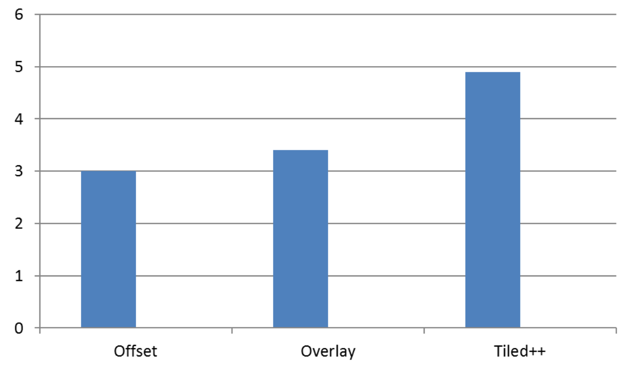



Figure 3.9: Comparing the user perception experience during the *Pong* task [ETO+10].

In terms of *task completion time* depending on the visualization method, the results demonstrated to be of significance, $F_t(2, 57) = 16.01$, $p_t < 0.001$.

The Tukey's HSD (**H**onestly **S**ignificantly **D**ifferent) post-hoc test furthermore points out significant differences of the *offset* & *overlay* methods, and the *overlay* & *Tiled++* methods. However, the comparison of the *offset* & *Tiled++* method revealed no significant differences.

Having a closer look at the captured *error rates*, the findings coincide with those of the *task completion time*, for example: $F_e(2, 57) = 19.52$, $p_e < 0.001$.

The outcome of this specific task has been congruent with the assumptions accepted before the evaluation.

(a) Assumption 1: *overlay* approach is very hard on users, especially if users have to compensate the large bezel crossings of four adjacent displays.

(b) Assumption 2: *Tiled++* will outperform the other methods, because there is no visual gap. Users will not have to compensate the missing image information or consider the offset, when crossing display areas.

(c) Assumption 3: *offset* approach will beat the *overlay* approach, since no image information is lost, using this approach.

| Approach | Mean time (s) | Standard deviation of time (s) |
|---|---|---|
| Offset | 142,5 | 56.95 |
| Overlay | 263.15 | 142.40 |
| Tiled++ | 109.05 | 33.25 |
| | **Mean error rate** | **Standard deviation of errors** |
| Offset | 15.95 | 16.02 |
| Overlay | 40.70 | 23.47 |
| Tiled++ | 9.45 | 5.26 |

Table 3.2: Averages and standard deviations of performance time and error rates for HotWire [ETO+10].

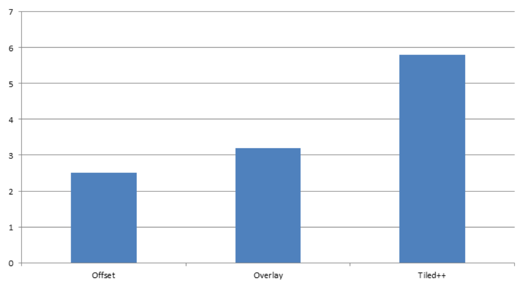
Tiled++ is providing a straight forward approach, by projecting low-resolution image information onto the bezel areas. Users do not need to think about reconstructing the hidden image information (a Poggendorff-like effect) or compensate the slight deformations when using the *offset* approach.

Not only the *error rates* have been captured during the evaluation, in addition the position where the errors occurred also have been recorded. With the *overlay* approach 89% of the errors occur at the edge of the display areas, at the bezel areas.

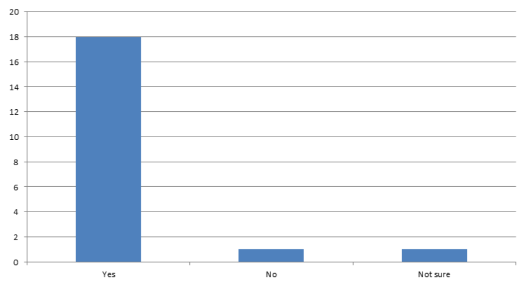
Counter-intuitively, there has been no significant difference between the *offset* & *Tiled++* approach. The offset effect had no grievous effects on user navigation from display to display. The *HotWire* task demonstrated that a complete image is crucial for task completion time, as well as error rate. The *overlay* approach has been the only method hiding image information and proved being both the less *effective* and the less *efficient* method for precise navigation across display borders. Using the *overlay* approach for such a task, it also can be very frustrating for users, making it the less favourable method in terms of *User satisfaction*. Contemplated from the viewpoint of *Usability*, the *Tiled++* method is the best method in regard to *Effectiveness*, *Efficiency* and *User satisfaction* (compare Figure 3.1).

### Lessons learned from the perception tasks

From the two performed perception tasks the *Poggendorff* optical illusion experiment revealed distinct perception effects. The test candidates indicated to have serious problems in connecting the diagonal lines across the display borders. The thereof resulting understanding can not be ignored when designing applications for LCD-based tiled display environments. If no color is used to support the users in their tasks, the offset approach makes it nearly impossible to find the appropriate diagonal line on the adjacent display.




(a) User perception during the *Poggendorff* task.




(b) User efficiency during the *Poggendorff* task.

Figure 3.10: Both perception and efficiency are positively influenced by the Tiled++ approach [ETO+10]. (a) Tiled++ is improving perception of users. (b) Tiled++ is improving performance of users.

Users first have to understand the system how the *offset* approach works and therefore deals with the position of the diagonal on the adjacent screen. After this *learning period* user also were able to work with the *offset* approach. Nevertheless the *Tiled++* approach does not need a training or learning period, since all image information is readily available to the users, increasing overall performance and reducing training time to the absolute minimum.

The test candidates favoured the perceptual experience as well as the greatly increased efficiency of the *Tiled++* approach, when working with the *Poggendorff* Illusion on the LCD-based tiled display wall, as seen in Figures 3.10(a) & 3.10(b). On a rating scale, ranging from 1 (poor) to 6 (excellent), Tiled++ has been rated with an average of 5.56, followed by the overlay approach (with an average of 3.25) and the offset approach (with an average of 2.55) (compare Figure 3.10(a).

Although not explicitly measured and recorded, 90% of the test candidates assured an efficiency boost, when using the *Tiled++* approach, as seen in Figure 3.10(b).

Contrary to perception task 01, the *Poggendorff* Illusion, task 02 is a "dynamic" perception task, featuring a simple animation sequence. The results of this task have been not that distinctive (compare Figure 3.11).

Test candidates favoured the approaches not distorting the image. Both the *Tiled++* and the *overlay* approach have been rated significantly higher than the *offset* approach, deforming the image. On a scale from 1 (poor) to 6 (excellent), the ranking has been: Tiled++ (5.3), overlay (4.45) and offset (2.25). The Tiled++ approach can be improved, since focus only was on a basic geometric alignment.

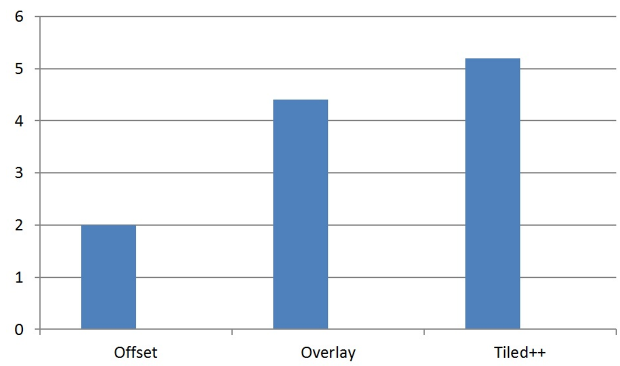



Figure 3.11: Comparing the user perception experience during the *Animation* task [ETO+10].

Therefore the transition from LCD area to the projection area still is clearly recognizable by the users.

The major finding from the animation task has been the understanding that, if showing animations or movies, the bezel problem is not noticed that much, because the content displayed is dynamic and changes rapidly so that the audience does not pay attention to detail. Furthermore the audience usually is not that close (e.g. signage screens). Details do not matter that much, missing image information becomes acceptable, however deformations seem to be less acceptable.

### Lessons learned from the questionnaire

In addition to the findings already presented, the test candidates were asked to provide honest feedback by filling out a short questionnaire. In addition to rate their experience with the evaluation tasks, the probands also were asked to provide detailed feedback on the Tiled++ approach. The key remarks have been:

(a) Using the bezel area as projection space and therefore providing additional image information has been rated positively by the majority of test candidates.

(b) Despite the fact of only providing a basic geometric alignment, the Tiled++ prototype was perceived as a seamless display.

(c) Unexpectedly, none of the users complained about the lower resolution of the projector and the resulting difference between bezel area resolution and screen resolution.

(d) The majority of test candidates (70%) stated to use Tiled++ again, on a LCD-based tiled wall system. The remaining 30% have been undecided.

(e) 90% of the probands stated, that Tiled++ provides additional benefits, compared to existing approaches. The remaining 10% have been undecided about the Tiled++ approach.

(f) In summary the feedback for the Tiled++ approach was predominantly positive.

Since the prototype of Tiled++ only featured a basic geometric calibration, a major point of criticism has been the non-existing calibration in regard to color and brightness. The difference between the projector and the LCDs has been obvious and has been a major issue during the animation task. This became clear during the video sequence. Users could focus on the animation, without having a real task, so the lack of calibration was revealed.

## 3.4 Evaluation for Design

In the concept phase for the development of an alternative GUI layout and interaction metaphors, tailored to Virtual Reality (CAVE) environments, an informal evaluation was conducted. Existing interaction mechanics were evaluated in order to verify early assumptions and design considerations by an independent group of

| **Test Environment** | **Visualization** | **Resolution** (pixel) | **Interaction device** |
|---|---|---|---|
| CAVE | 3D | 1366x1024 | Flightstick |
| CAVE | 2D | 1366x1024 | Flightstick |
| Desktop | 2D | 1366x1024 | Keyboard & Mouse |

Table 3.3: Comparison of evaluation stages [Ole12].

users. A virtual globe application was utilized for the interaction tasks. The application is based on the **V**irtual **R**eality **U**ser **I**nterface (VRUI) development library. The framework will be used for future collaborative development projects, in view of that fact the GUI and general interaction mechanics, provided by the VRUI framework, were investigated in order to determine potentials to propose improvements, regarding usability. Although the VRUI framework is providing excellent functionality, current users are overwhelmed and struggle in mastering interaction with the VRUI applications.

The overall goals are:

(a) use the VRUI framework as a common basis for future software developments.

(b) utilize VR applications for collaborative tasks.

(c) improve usability.

### 3.4.1 Goal of the evaluation and Experimental Design

The goal of this informal evaluation during the design phase was not gaining "hard data". Main purpose has been to receive feedback of other users and to verify if other users also struggle with the shortcomings of the existing interaction mechanics, already determined during an early concept and brainstorming phase. Although measurement data from two interaction tasks has been gathered, the findings from the questionnaire, collecting opinions have been more interesting. The findings have been conveyed into first concepts (compare [Amr12] and the *ARC* metaphor, Chapter 4.5).

### Experimental Design

The Experimental design consists out of two interaction tasks, namely the *navigation* task and the *GUI* task, carried out on three stages (*test environments*), compare Table 3.3.

(a) VR environment, CAVE. User interaction device for both interaction tasks has been a *Flightstick*. The user is tracked (glasses & flightstick) and experiences **3D** during both tasks.

(b) VR environment, CAVE. User interaction device for both interaction tasks has been a *Flightstick*. The user is tracked (glasses on head, although not looking through them & flightstick) and experiences **2D** during both tasks.

(c) Regular desktop environment, single LCD. User interaction device for both interaction tasks has been a regular *keyboard & mouse* setup. The user experiences **2D** during both tasks.

In order to reduce potential variables the resolution has been adjusted to be equal, at all three evaluation stages. Variables have been the interaction devices and the visualization methods (2D versus 3D), in order to gain insight of potential issues regarding these two variables. Considering the fact of a more or less *informal evaluation*, the variables can be neglected.

Each user has been provided with a short, individual training period, in order to familiarize with the evaluation environments and basic interaction mechanics.

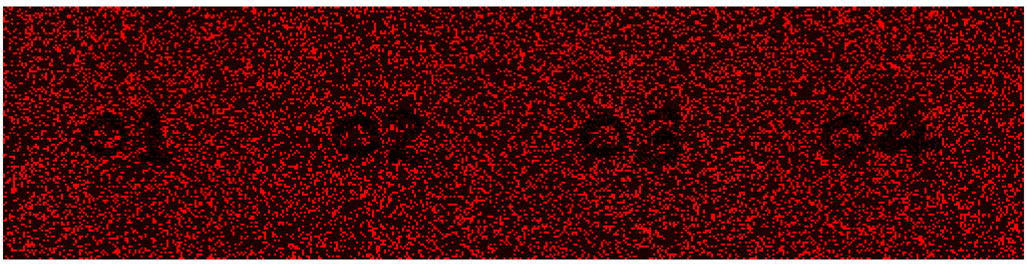


Figure 3.12: Textures used for the navigation task [Amr12].

#### Population of evaluation

A total of 11 test candidates accepted to participate in the evaluation study. Out of the 11 candidates there have been 10 male and 1 female participants.

The probands have been recruited from the computer science department and the mechanical engineering department, so a familiarity with computers can be anticipated.

6 out of 11 test candidates have no experience in Virtual Reality environments. 5 probands previously have had work experience in VR environments.

The age range has been from 25 to 36 years (average 30.18 years).

#### The *navigation* task

During the *navigation* task, users have to interact with a virtual globe application. The test candidates can interact with the virtual globe application by zooming, panning, rotating the virtual globe, in order to spot arbitrary placed polygons with number textures.

In order to complete the task, users have to

(a) spot the polygons, after rotating & panning the virtual globe.

(b) zoom in, to be able to verify the numbers and read the numbers out loud.

In order to *force* the test candidates to make use of the navigation features the application offers, the textures used on the polygons are hard to read from distance, so that users have to zoom in very closely, as seen in Figure 3.12.

The users performed this task on all stages in arbitrary sequences. The time the users need to spot two polygons and give positive identification of the two numbers was measured (compare Figure 3.13(a)).

#### The *GUI interaction* task

To complete the *GUI* task, the test candidates worked with the application's GUI. The task is to make use of the measurement tool, a functionality implemented in the virtual globe application. With the measurement tool, the user's task is the measurement of the distance between the two polygons, spotted in the *navigation* task.

(a) A test candidate performing the navigation task in the CAVE, FBK, University of Kaiserslautern.

(b) A test candidate is performing the GUI interaction task in the CAVE, FBK, University of Kaiserslautern.

Figure 3.13: Experimental design to evaluate user interaction & performance while performing two tasks using three different display environments and interaction devices [Ole12]. (a) The *navigation* task, testing user interaction with a standardized application setup. (b) The *GUI interaction* task, testing feasibility of the GUI in three evaluation stages.

The test candidates therefore had to use one functionality of the virtual globe application, besides basic navigation functionality. To access this feature, the probands had to interact with the GUI and the therein embedded menu structures, as seen in Figure 3.13(b).

The task completion time has been recorded.

### The questionnaire

The evaluation run was secluded by a questionnaire, which the test candidates answered after the performance of the two interaction tasks, on all three stages.

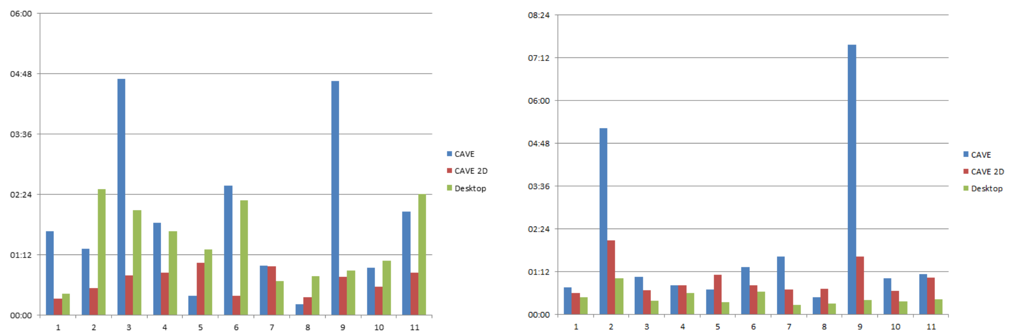
The questionnaire contained task related questions, with intention to gain insight on the user experience and also questions on how to improve the user experience.

### 3.4.2 Results of the Evaluation

After the evaluation, the captured data as well as the questionnaires have been analysed and interpreted. Since the conception of the evaluation as an informal evaluation, in a very early stage, a ANOVA approach has been waived.

#### Lessons learned from the *navigation* task

The time data collected for each test candidate at the navigation task stages is pictured in Figure 3.14(a). One can spot two obvious outliers (test candidates 3 & 9). In order to get proper results, the two outliers have been eliminated for calculating the average, as seen in Figure 3.15(b).

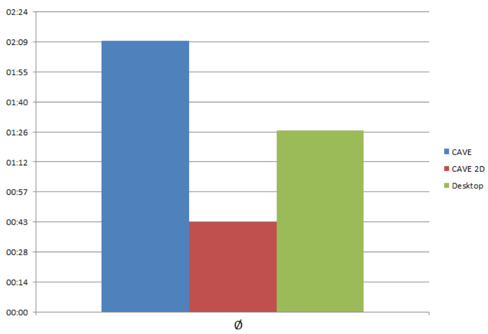



(a) Navigation task results per test candidate.

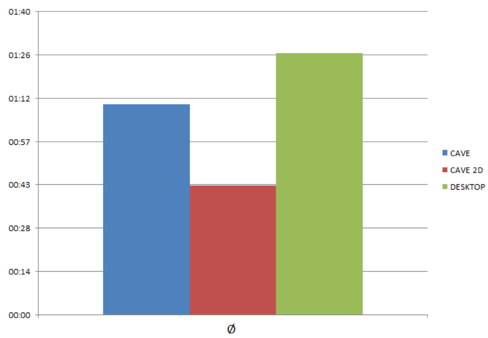
(b) GUI task results per test candidate.

Figure 3.14: Test results per individual test candidate for the *navigation* and the *GUI* task (CAVE **blue**, CAVE 2D **red**, Desktop **green**) [Ole12]. (a) Test results per individual test candidate for the *navigation* task. (b) Test results per individual test candidate for the *GUI* task.

For record purposes the *unfiltered* average data, including results of all test candidates, is depicted in Figure 3.15(a). Eliminating the outliers leads to a different result: average task completion time has been slightly lower in the CAVE environment, using the flightstick (blue bar). However, the test candidates performed best in a 2D environment using the flighstick interaction device (red bar). During the desktop stage (green bar), using traditional keyboard & mouse interaction, the test candidates revealed the worst performance.




(a) Navigation task: average of the results (including outliers).




(b) Navigation task: average of the results (without outliers).

Figure 3.15: Average of the test results for the navigation interaction task (CAVE **blue**, CAVE 2D **red**, Desktop **green**) [Ole12]. (a) Average of the results conducted during the *navigation* task (including outliers). (b) Average of the results conducted during the *navigation* task (after eliminating outliers).

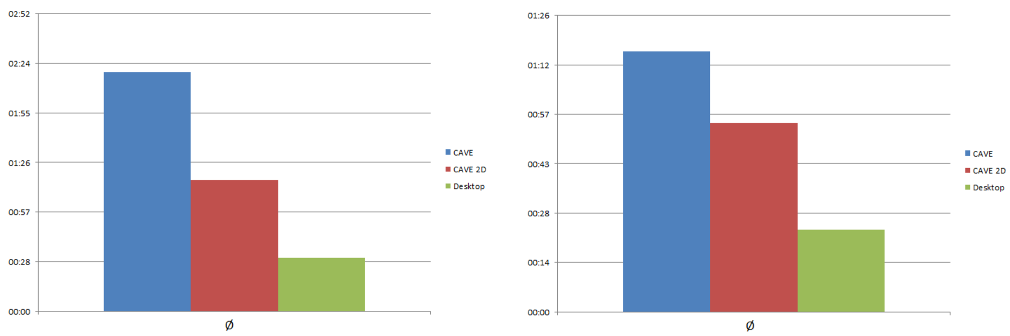
The results can be interpreted in the following way: the navigation task does not need very precise interaction (like selecting the appropriate function from a menu). The navigation task has been executed by using intuitive flightstick commands for the task necessary interactions *pan*, *rotate* and *zoom*.

The three-dimensional representation during the Virtual Reality CAVE stage seemed to be irritating for some test candidates, since performance has been slightly behind the performance of the CAVE 2D stage, using the same setup, just without 3D visualization.

### Lessons learned from the *GUI* task

The task completion time recorded during the GUI task stages also revealed two outliers, as seen in Figure 3.14(b) (test candidates 2 & 9). Eliminating both candidates, for the calculation of the average results per stage (Figure 3.16(b)) revealed no shifting of results (compare Figure 3.16(a) for *unfiltered* average results).

As expected, the evaluation revealed, the test candidates performed best using the traditional desktop environment with keyboard & mouse interaction. Second best results have been achieved by the CAVE 2D task stage. The CAVE task stage again performed not that good.




(a) GUI task: average of the results (including outliers).

(b) GUI task: average of the results (without outliers).

Figure 3.16: Average of the test results for the GUI interaction task (CAVE **blue**, CAVE 2D **red**, Desktop **green**) [Ole12]. (a) Average of the results conducted during the *GUI* task (including outliers). (b) Average of the results conducted during the *GUI* task (after eliminating outliers).

Since the graphical user interface of the virtual globe application is based on a traditional desktop GUI, with over-boarding menu structures (compare Figure 3.13(b)), the logical assumption has been, that interaction will be more comfortable with the traditional interaction devices.

In addition, the flightstick offers significantly less *precision* in the selection of a function out of the menu or the selection of two measurement points (task of the GUI evaluation), if compared to a regular computer mouse.

In both the *navigation* as well as the *GUI* task the least favourable user performance has been recorded in the CAVE setting. If there is a connection between the slow task completion times and VR 3D visualization should be topic of a further, more in depth research.

Nevertheless the GUI task revealed, that the existing GUI has to be improved, in order to improve user interaction capabilities with the tracked flightstick device, in order to compensate for the precision issues. The GUI of the VR environment should consider the interaction device, which in VR environments most likely will not be a precise computer mouse.

For basic navigation tasks, where precision related issues are of no great importance, a flightstick seems to offer a more intuitive way of interaction.

**Lessons learned from the questionnaire - Feedback**

The evaluation has been carried out after already having some basic assumptions, conducted during brainstorming processes and thoughts on how to improve the existing methods of interaction, especially regarding the graphical user interface.

By answering the questionnaire after experiencing both tasks, using different stages, the test candidates have provided feedback. Contrary to the test results, where the CAVE proofed to be be the less performant stage, most test candidates rated the user experience as good and the navigation experience as intuitive. The VR effect, with user immersion and the three-dimensional representation of the virtual globe, has been rated as impressive, although test candidates state, that a longer training period is necessary to get used to the VR environment.

The majority of probands have showed great disapproval for the menu structure of the GUI. Both the amount of functionality has been criticized as well as the limited precision of the flightstick to browse through menu structures, in order to select the desired function.

The findings of the questionnaire have been of subjective nature, but provided insight on user experience and opinions on where potential, to improve the user experience, is given.

## 3.5 Improving objectivity by measuring subjectivity: utilizing a commercial EEG-headset for evaluation support

With the introduction of the Emotiv EPOC neuroheadset, a State-of-the-Art interaction gadget was released to the consumer market in 2009, offering new interaction possibilities.

However, the wireless Electroencephalography (EEG) device's area of application is not limited to interaction purposes. Furthermore it can be used as an evaluation support device [COEK12], in order to address the *polite test candidate* problem.

Preparing and conducting user studies and evaluations is a time consuming process. In some cases the outcome is unexpected or in a worse case scenario is not useful at all. In addition some evaluation techniques come along with disadvantages, which can influence or even falsify the outcome of the evaluation.

Figure 3.17: Test candidates with the Emotiv EPOC, a commercial wireless EEG headset used for measuring subjective parameters during tasks [COEK12].

The *thinking aloud* method can be regarded as a less favourable method, since the verbalization of thoughts, as well as emotions can affect the test candidate's behaviour and reactions.

In order to utilize the EPOC headset for evaluation purposes and therefore gain additional insight regarding the user experience, the EPOC device has been tested to validate its usefulness.

The detection of both *facial expressions* as well as *emotional states* delivered encouraging results (compare Figure 3.17).

By applying a neuroheadset to probands during evaluation tasks, e.g. interaction tasks, additional data can be captured, in order to determine at which stage of the evaluation the user had problems in completing the task, but did not reveal design flaws, due to the *polite test candidate* problems. This can be an additional value, besides the usual data collected during evaluation scenarios (e.g. task completion time, error rate) and questionnaires.

The question of *"What do you really think about our product?"* can be addressed by the utilization of EEG-based headsets, in order to measure and verify subjectivity and to receive more objective, more clear evaluation results.

## 3.6 Summary

Evaluations and user studies are a crucial factor when it comes to develop user-centered applications or new methods and to verify their usability. In this chapter, two evaluation examples provided insight on how evaluations can be set a up.

During the formal Tiled++ evaluation the number of variables that influence usability has been carefully limited, since focus on this specific evaluation has been on the impact of the bezel problem. The evaluation compared existing methods on how to deal with the undesired bezel effect with the new Tiled++ approach. In order to get clean results, the user interaction devices of choice have been keyboard & mouse, devices the test candidates are familiar with (at least this has been the assumption). The tasks also did not demand complex user interaction, so the training period could be neglected. The visualization or representation of the task applications have been simple, in order to provide clarity; the probands have been able to focus on perception issues, related to the three methods used, to deal with the bezel areas. By doing so, a deeper understanding of user perception and also hard data has been gained during the evaluation process, which both provided valuable information for further research and developments.

The second evaluation, with the goal to gain more in-depth insight on the interaction mechanics provided by the VRUI framework, users participated in two tasks, interacting with a simple VRUI application in different environments. The goal has not been the verification of the interaction mechanics provided by the VRUI framework, focus has been on the user's opinion, especially in regard to the graphical user interface. The evaluation also revealed a discrepancy of measured data and user perception. Although the average navigation task completion time in Virtual Reality has been slower, compared to the other two stages, users actually did like the three-dimensional representation and the intuitive navigation interaction, although user performance measurements would indicate other results. My findings findings from the evaluation have been used to improve the graphical user interface, which, especially in the CAVE environment, hampered the user's work flow. With the evaluation deficits have been revealed and therefore could be improved by my conceptional design of the *ARC* GUI metaphor.

The advantage of conducting user studies and evaluations is the immediate oral feedback given by test candidates, which can be very helpful and reveal other perspectives. Subjective opinions and findings not necessarily have to be ruled out, in fact they can provide essential benefits.

In order to provide a product (e.g. software, hardware, concept, idea), user studies and evaluations are an essential element throughout the product's life cycle.

# Chapter 4

# GET ACTIVE! - INTERACTION WITH ARBITRARY DISPLAY ENVIRONMENTS

## 4.1 Introduction

The Cambridge dictionary provides two definitions for the term *interaction*:

*"interaction:*

*1. when two or more people or things communicate with or react to each other.*

*2. when two or more things combine and have an effect on each other."* [1]

Traditional interaction devices (e.g. non-wireless keyboard and mouse devices) still are feasible for desktop systems. For new display environments, at public places or collaborative work environments, traditional interaction devices are not suitable and would counteract the advantages of modern Information Technology (IT) environments.

[1] http://dictionary.cambridge.org

The field of Human-Computer Interaction (HCI) is becoming more and more important, due to the high demand of intuitive and usable interaction methods. On the one hand new display environments require for new methods of user interaction possibilities, on the other hand, due to the continuous developments in the field of mobile devices, the field of mobile HCI is evolving and therefore opens up new options for intuitive and usable interaction techniques.

The field of mobile HCI will be a decisive factor for future developments and also *sculpt* the field of HCI. The individual's mobile devices, like a tablet PC or a smart phone, have evolved from idle *everyday objects* to *lifestyle devices*, offering the functionality users expect from desktop PCs.

HCI aspects can be experienced in everyday life:

1. buying a train ticket, users most likely will interact with public touch screens
2. using you mobile phone or your tablet PC
3. using your TV
4. supermarket checkout
5. navigation system and radio in cars
6. etc.

In this chapter I introduce interaction techniques, the utilization of mobile phones, which proofed to be very successful, in regard to both large display environments and public display environments. Furthermore I present an interaction concept for VR environments, with the goal to support users in their interaction tasks and to enhance usability.

## 4.2 State of the Art

A general overview of smart phones as ubiquitous interaction devices is provided by Ballagas et al. [BBRS06]. Hagen et al. also provide insight on the area of *Mobile*

*Human-Computer Interaction* [HRKS05]. A survey on the impact of mobile phone technology and everyday life has been conducted by Lane et al. [LML+10].

Van Biljon and Kotzé [vBK07] lay the focus on how likely users want to adapt to new technologies, in particular to mobile phones and what the determining factors are, also considering social factors.

The combination of mobile phone interaction and gestures is presented in the work of Bhandari and Lim [BL08].

Bhatia et al. present *Malleable Interactive Software Toolkit* (MIST), in order to enhance and facilitate the development of user interfaces ( [BMN]. As an ultimate goal (long-term) the authors formulate, that even unskilled users should be able to adjust user interfaces to their specific needs.

Unlike most approaches that do exploit mobile phone technologies for direct interaction and as an interaction device, Drewes et al. [DDLS07] propose eye gaze interaction to interact with the mobile phone itself.

Holleis et al. conduct an evaluation on how applications can profit from additional keypad functionality [HHH08] and performance [HOHS07].

Miluzzo et al. present *Darwin* [MCR+10], a general framework to improve machine learning on sensor-enable phones.

Roduner [Rod06] argues that mobile phone interaction is a ”do-it-all” solution.

In *The Magical Number Seven* Miller [Mil55] points out the limitations which interaction developers should consider today. To much complexity will make interaction cumbersome and will lead to failure, e.g. when being forced to remember too many gestures.

Interaction with tiled display environments is challenging. Traditional keyboard & mouse interaction would counteract the advantages of large high-res display environments.

The correlation study the correlation of display size and enhanced user interaction is studied by Tan et al. [TGSP04]. The work of Robertson et al. illuminates the large display user experience in general [RCB+05].

Ball and North show how high-resolution tiled display environments effect both visualization and navigation tasks [BN05b]. In addition [BN05a] they provide a formal user study, examining the effects of high-resolution tiled display walls further. In [BN08] Ball and North conduct a research on the factors crucial to increased user performance with large displays. Both the peripheral vision as well as the physical navigation capabilities, enabled by the large displays, are observed. The relationship between display size and user performance attributable to the physical navigation capabilities have been research topic in [BNB07]. Physical navigation in front of large, tiled display walls is also research topic of Peck et al. [PNB09]. Czerwinski et al. [CSR+03] point out the productivity benefits of large display environments, focusing on the aspects of screen real estate. The effect of superior resolution is not considered in this research paper. Birnholtz et al. [BGMB07] show the effects of collaboration in front of large displays in order to negotiate a task and find consensus, one of the major advantages of large screen displays.

Bezerianos [Bez07] evaluates different approaches to address the problem of user interaction on large wall displays. Alternative views, layout of windows and switching between different tasks is examined. In previous work *Vacuum* has been introduced [BB05]. With *Vacuum* the issue of accessing out-of-reach content is addressed. With *Mouse Ether* [BCHG04] Baudisch et al. present an approach to eliminate the warping effects user experience when crossing monitor bezels.

Belt et al. [BGHM06] compare the interaction performance and user preferences of tag-based interaction. Visual tags and RFID tags are compared, with the result that most users have not been familiar with functionality and concept of tags.

The issue of users unfamiliar with NFC/RFID technology is also addressed by Broll et al. [BKHB09]. The goal of the paper is to increase learnability and to provide guidance. A user study was conducted to verify the proposed strategies.

Madhavapeddy et al. propose the utilization of mobile phones to enhance human-computer interaction [MS04]. The authors use both camera and Bluetooth capability of the mobile phone for interaction. The camera is used to scan and decode visual tags. Barcode recognition, namely *European Article Number* (EAN) and *Quick Response Code* (QR code), by using camera equipped mobile phones is introduced by Ohbuchi et al. [OHH04]. In the paper the performance of the image processing capabilities is benchmarked. Chaisatien and Akahorie conduct a pilot study on the usage of QR code [CA07]. By scanning the QR tag with a mobile phone camera, the user is forwarded to the homepage encoded within the tag without the need to manually enter an URL (Uniform Resource Locater). The authors propose the introduction of QR code for education purposes. Lui et al. are researching QR code recognition issues under varying conditions [LYL08]. The authors describe a new image recognition algorithm in order to improve QR code readability by mobile phone cameras under varying lighting conditions.

Ahlborn et al. present laser pointer interaction for large display environments [ATK+05]. The focus on the paper is on the dot recognition algorithm.

The *Soap* device is tailored to be used with large displays [BSW06]. *Soap* is a mid-air-mouse, enabling the user to perform mouse interaction (pointing, clicking) mid-air. The user is not bound to a desk or table, he can use a mouse and also physically navigate in front of large display environments.

Seokhee et al. [JHKB06], [JHKB10] propose hand held devices (in both cases camera equipped mobile phones) for user interaction in large display environments.

Accelerator-based gesture controls are proposed by Kela et al. [KKM+06]. The authors did an user study in an design environment, with the findings that gestures offer a natural interaction modality, which can be extended with other modalities, like RFID or speech commands.

Spotlight, a attention guiding system, highlighting a certain part on large, high-resolution display environments, is introduced by Khan et al. [KMFK05].

Shirazi et al. introduce *Flashlight interaction* [SWS09]. The flashlight of mobile phones is used to interact with large screens.

Ball et al. [BCHG04] have done a research on embodied interaction techniques applied to large displays.

Ebara et al. propose tele-immersive collaboration in tiled display environments using high-resolution video [EKLK07], [ES09b].

Fass et al. present *MessyBoard & MessyDesk* [FFP02]. The authors exploit spatial memory with a shared projection space, where users can share content in an office environment.

When it comes to interaction with public displays, the mobile phone also is a versatile interaction device of choice. In the following an overview about closely related work is provided.

The deployment and integration of public displays in urban environments is topic of Hosio et al. [HJK+10]. Mobile clients (mobile phones) are used to interact with the prototype application. Sas and Dix provide a general overview about interaction as well as evaluation techniques of mobile phone interaction with public displays [SD08].

Boring et al. introduce a camera based interaction metaphor (*shoot & copy*) for mobile phone interaction with public displays [BAB+07]. The interaction technique is used to transfer data between mobile phone and public display. In [BJB09] Boring et al. utilize the gravity sensor of mobile phones to interact with public screens.

Dachselt and Buchholz introduce natural mobile phone gestures to interact with distant displays [DB09]. A *throw* gesture, for example, is used to transfer data from the mobile phone to the display. A prototype with several application examples is presented.

Ballagas et al. [BRS05] introduce the *sweep* and *point & shoot* interaction metaphors. *Sweep* uses optical flow image processing and the mobile phone can be used to control a mouse cursor on a public display. With the *point & shoot* technique the user utilizes the camera and visual tags on the display to select content.

In the work of Cheverst et al. [CDF+05b], [CDF+05a] Mobile phones are used to interact with Public Displays. The authors propose Bluetooth technology for connecting the phones to the displays, due to minimizing connectivity costs for users.

The *Notification Collage*, introduced by Greenberg and Rounding [GR01], is a groupware system to share information on a collaborative surface in an office environment. The users interact with each other, so social interactions can be started by virtual interaction (e.g. posting a picture or video).

Haritaoglu and Flickner [HF02a] present *Attentive Billboards*. A algorithm extracting and analysing customer behaviour in front of public billboards and also providing basic information about the customers is used. With the gained information conclusions can be drawn to optimize advertisements displayed on public billboards.

Peltonen et al. [PKS+08] conducted a study on how users interacted with a public display wall, the *CityWall*, set up in Helsinki, Finland. The user study is based on 1199 people who interacted with the public display setup an have been monitored by doing so (video). The authors conclude that public displays can become meeting and interaction spaces for real world interaction, communicating with other users and therefore support social learning.

In the work of Hardy et al. [HR08a], [HR08b] *Near Field Communication* (NFC) is introduced. The *touch & interact* metaphor is used to interact with a tourist guide application, displayed on a public screen. Seewoonauth et al. [SRHH09] use NFC technology to exchange picture data between display and mobile devices.With the proposed *touch & connect* and *touch & select* techniques transferring image data should be more user friendly and convenient. Hardy et al. [HRWP09] continue the work on NFC interaction techniques and also conduct an evaluation on the NFC interaction techniques. In [HRHW10] Hardy et al. compare NFC interaction with static (e.g. posters) and dynamic (large NFC displays) environments.

Zong et al. present *Doodle Space* [ZLFS09], allowing users to use mobile phones as painting devices on a public display wall. The authors intend to get people not knowing each other, communicate with each other, by providing an easy to use application to share content in public spaces.

In Virtual Reality (VR) environments users often face interaction issues. Coming from desktop environments, most users are habituated to keyboard/mouse interaction. Therefore the design of VR GUIs as well as interaction metaphors is more tedious.

The work of Preddy and Nance [PN02] provides a broad overview of requirements for human interaction with application in VR environments. Tedjo-Palczynski et al. [TPHW+09] introduce specifications for interaction techniques with scientific visualizations in VR. Martinez et al. [MLM+11] analyse existing existing tools that deal with the development of VR interaction applications and reveal a guideline/framework based on their findings, demonstrated in a sample application.

An evaluation comparing real world interaction with those in VR environments is conducted by Sutcliffe et al. [SGFT06].

Figure 4.1: VirtuSphere, a 6DoF VR interaction sphere. In this application scenario, VirtuSphere is utilized for military simulation purposes. *Image courtesy of VirtuSphere.*

Tan et al. [TCR06] how large displays can minimize the gender gap in Virtual Environments (VE).

Ciger et al. propose the usage of a *Magical Wand* as an interaction device in VR [CGVT03]. Their approach combines a pointing device (the Magical Wand) with speech recognition (approximately 17 words and expressions). Considering the amount of speech commands combined with the pointing capabilities of the wand, users might be overwhelmed by this approach, especially when considering the work of Miller [Mil55].

Moritz et al. [MWM05] present an interaction technique to explore cardiovascular structures in VR. Their approach features a gamepad to control the virtual camera moving through the vascular structures.

In the work of de Haan et al. [dHGP08], the Wii-Balance Board™is used for interaction in VR environments as a cost-efficient device for navigation or task switching.

Arsic et al. [ARW$^+$10] propose the utilization of infra-red tracking system in order to enhance user tracking when using gesture based interactions, e.g. with a Wii Remote™.

McCrae et al. [MMGK09] present a Multiscale 3D navigation approach. *HooverCam* can be applied for object inspection in 3D environments and *look-and-fly* for enhanced navigation. Although not explicitly tailored for VR applications it can be utilized for it.

With *VirtuSphere* [2] an innovative approach to interact with VR environments is presented. The user is utilizing a wireless Head-Mounted-Display (HMD) from within the VirtuSphere (Figure 4.1). The sphere has tracking sensors attached and is mounted on roller bearings, allowing *360 degree of movement/6 degrees of freedom* (6 DoF). The user inside the VirtuSphere can explore VR environments by walking, jumping etc., basically mimicking real life movements and therefore providing a very natural interaction metaphor to explore VR.

## 4.3 Interaction principles for large display environments

Large screen setups combine screen real estate and high-resolution and therefore provide for environments, suitable as collaborative work spaces. Multiple users are able to access the display area, utilize the work space for collaborative tasks in front of the screen area, as well as to discuss lessons learned with other users. Traditional interaction devices like *keyboard* & *mouse* interaction *have past one's best* (they are outdated).

Large display environments are predestined for mobile HCI metaphors. The users have their mobile interaction device at hand, since collaborative work environments are also flexible work environments, contrary to classic cubicles (single-user work spaces). Furthermore users can exploit physical navigation and utilize spatial memory, an important factor in regard to usability criteria.

Massive pan & zoom operations are not necessary any more or are at least reduced to a minimum, because the large high resolution displays are capable of offering focus & context information at the same time (Figure 4.2). Users can focus more

[2] http://www.virtusphere.com

on their task, like examining data or other more essential tasks, than on navigation or adjusting views.

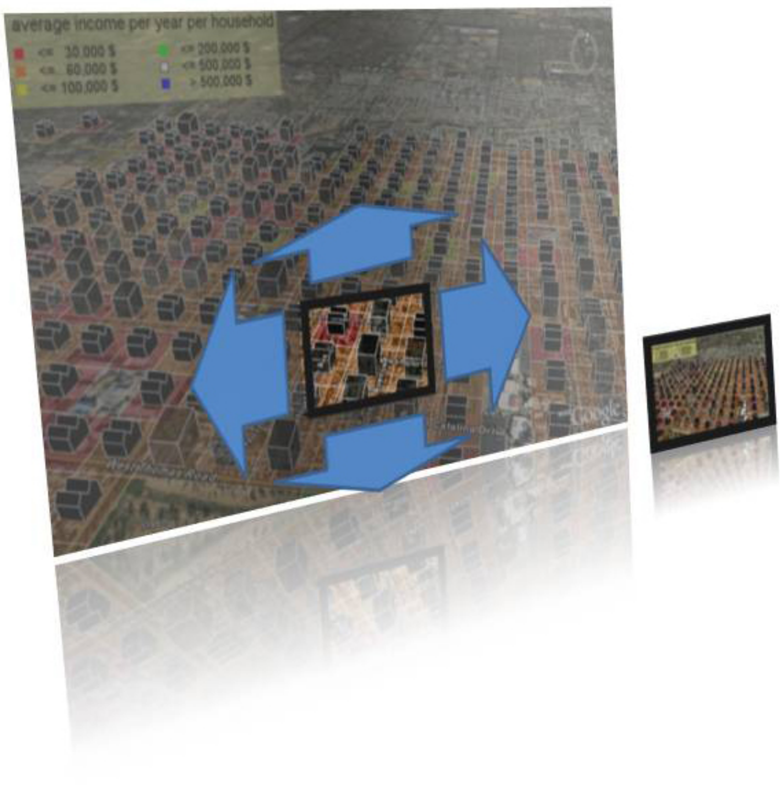



Figure 4.2: Comparison of pan & zoom operations on large display versus small display environment. The large display can provide focus **and** context information at the same time, accessible by simple navigating to the point of interest (physical navigation), whereas the small screen only can provide focus (detailed information) **or** context (overview information) views [Ole12].

In addition, collaborative work also enhance *human-human interaction*, face-to-face discussions, in front of the display, are enabled (compare Figures 4.3(a) and 4.3(b)). Providing users the ability to discuss insights immediately, team work, especially in interdisciplinary teams, cooperation becomes fruitful.

The capabilities of large, high-resolution tiled display walls go way beyond those of *presentation projector solutions*, known from meeting room environments. In such an environment one actor (the *presenter*) presents contents to an audience. These presentation environments also can be described as *static* environments, offering no real multi-user interaction, because of the simple fact: it is not their purpose. Tiled display environments can provide for *dynamic* environments, appropriating for interaction space (work space).

(a) Face to ...

(b) ... face discussion.

Figure 4.3: Large tiled display walls enable collaborative work and face-to-face discussion [Ole12]. (a) Content and findings can be discussed immediately. (b) Large display walls offer advantages, which traditional single user environments can not offer.

### 4.3.1 Interacting with the Tiled ++ Focus & Context setup - The *Human Zoom* metaphor

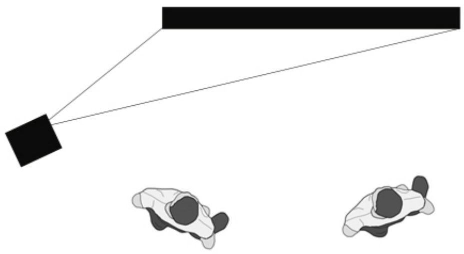
Large display environments enable physical navigation: the physical interaction metaphor *human zoom* can be applied with tiled display walls, utilizing the Tiled++ approach.

With the Tiled++ approach, an inverted focus & context display is created. The LCD screens act as focus areas, providing high-resolution information, whereas the bezel areas act as context areas, providing low-resolution context information, filling the semantic gap.

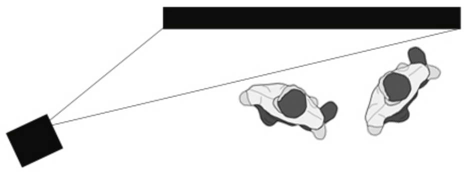
Due to the size of the display environment (even with a 3 x 3 setup), users can't access detail and overview information at the same time. By using the *human zoom* metaphor, simple physical interaction can be used to interact with the display in a very natural way.

By stepping back from the Tiled++ environment, the users are able to perceive an overview, as depicted in Figure 4.4(a).

By stepping forward, users are able to access details, as seen in Figure 4.4(b).



(a) Context view.



(b) Focus view.

Figure 4.4: The *human zoom* metaphor. Large tiled displays enable physical navigation as well as spatial memory [ETO+10]. (a) By steeping back, the context information can be accessed by the user. He can use physical navigation to switch between focus & context information. (b) By stepping towards the tiled display wall, the user can access more detailed information and focus on a special point of interest.

When accessing focus information, the low-resolution image information, projected onto the bezel areas, becomes secondary. Therefore the problem of users stepping into the projection beam, obscuring the context information, can be neglected. When stepping forward, the user is interested in accessing high-resolution details [ETO+10].

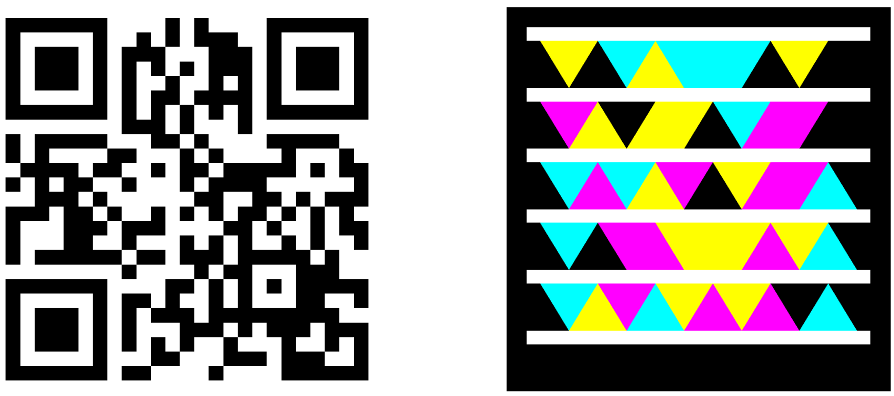
In addition, users not only are able to utilize the most natural zoom metaphor, *human zoom*, by utilizing of physical navigation with large screen environments, the user's spatial memory can be addressed, a further improvement in regard to work flow and therefore an usability enhancement. [OTM+09].

When using spatial memory, users can memorize the location of content on-screen. They are able to relate to specific content and screen position (e.g. *"in the up-*

*per right corner"*). By addressing the user's spatial memory, navigation tasks are enhanced (following Baddeley's model, also compare [Log95], [BSRB96], [TPSP02] and [TSP+02]). The significant reduction of navigation tasks, related to adjusting views and switching between focus and context information (permanent pan & zoom operations), is improving productivity in front of large screens, since users can focus on tasks (e.g. data mining), rather than struggling with navigation interactions.

### 4.3.2 Tag-based interaction featuring mobile devices

The tag-based interaction approach [TMM+09] allows for multi-user interaction in front of large screen environments.



(a) QR Code Tag.

(b) MS Tag.

Figure 4.5: Two kinds of tags. (a) The Quick Response Code Tag, a very popular tag. (b) The Microsoft Tag, an enhanced tag.

So called *Tags* are used to encode additional information within visualized content. Popular *Tags* are *Quick Response Code Tags* (QR Code Tags) (Figure 4.5(a)), simple two-dimensional tags and the enhanced *Microsoft Tags* (MS Tags) (Figure 4.5(b)), which are utilized in this scenario.

Since tag-based interaction enables multiple users to explore and analyse the visualized data simultaneously, tag-based interaction is a simple but yet a very effective and intuitive method of mobile HCI.

When spotting an area of interest, the user can decide to access more in-depth information. This is done by simply *scanning* the relating MS Tag with the mobile phone camera, similar to scanning a bar code. The user then has the choice to receive the in-depth information in a pop-up *information balloon* (see Figure 4.6(b)) on the tiled display wall (public) or on their private display, their mobile phone display.

With this approach a simple *user-group management* or *access-level management* is realized. Certain information can be restricted to specific user groups, as well as limiting the publication of certain detailed information on the public screen area. By doing so, sensitive information can be handled very effectively.

The data displayed on the cell phone is more substantial. For the displayed information an individual level of detail can be selected. The number of values can be set, by indicating an *information class* number. The level of information can be adjusted to perfectly suit the individual user's needs. With the *publish* function the content can be transferred to the public screen area, which is located at the rightmost column of the display wall, as seen in Figure 4.6(a).

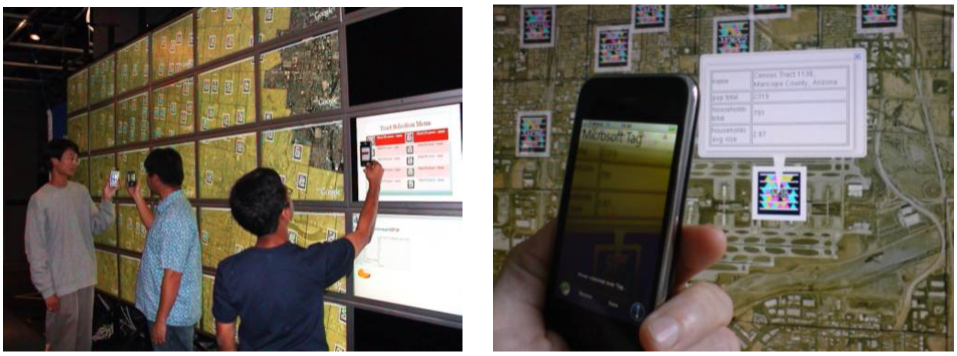
The public screen area is a designated area of the tiled wall, reserved to display information which typically only is visible on the private cell phone screen.

Users can initiate group discussions by publishing information on the public screen area. The published information is free for all and interesting findings can be discussed immediately.

The tag-based approach counteracts the problem of *information cluttering* and *information overload* by providing the users with *information on demand.*

Additional information is shown after the user actively requests this information by scanning a tag with his personal interaction device: a camera-enabled mobile phone.

With this approach the best of both worlds can be offered to the users: the geo-referenced visualization capacities of *Google Earth* and, on demand, precise data from census tracks. In addition the census track now is geo-referenced and stakeholders do not have to rely on more or less abstract tables without any geographic relation.




(a) Collaborative work. (b) Scanning tag.

Figure 4.6: The Microsoft tags are enabling multiple users to interact in front of large high resolution display walls [TMM+09]. (a) Multiple users are able to interact with the application in front of UC Irvine's HIPerWall. (a) A MS Tag is scanned with a mobile phone and an information bubble is providing information on demand to the user. By using tags the problem of information overload is also addressed by minimizing the visualized content.

## 4.4 User Interaction with Public Displays

Displays set up in public spaces, so called *Public Displays*, have been around for quite a long time. The displays main purpose has been signage and advertisement, not designed for extensive user interaction.

With traditional pinboards in mind, the Digital Interactive Pinboard (DIP) approach has been designed and implemented. The focus was not on the development of *information kiosk* approaches, providing users with rather limited interaction possibilities.

Instead the focus of the DIP approach was on the design and implementation of scalable public screens, allowing for mobile HCI. Users can access, contribute and share information with their own hand held devices, e.g. mobile phones. Users can interact with the screens in an intuitive way and social interaction can be facilitated, as an additional benefit.

### 4.4.1 Digital Interactive Pinboard Interaction

The functionality provided by the **D**igital **I**nteractive **P**inboard (DIP) approach [TCO+10] includes (compare Figure 4.7):

**Post**. The users are able to contribute to the DIP by using their mobile device. They can add files to the public pinboard, similar to submitting a posting to a Web-Log. The uploaded item/file/message can be further specified (*tagged*), by adding a predefined *characterization tag* (e.g. news, research, general announcement). The *characterization tags* not only provide a short overview about the general content of the deposited (uploaded) information, it also is used for the *filtering* & *highlighting* functionality, provided by the DIP framework. Since privacy always is an issue, especially with content shared on a public pinboard, the users can provide access rights and therefore specify a *level of privacy* for the information they share. By default, the items posted on the DIP, are shared with the entire user community (registered users). In order to make accessibility restrictions, the user can select from the registered users database, in order to grant accessibility rights to specific users only.

**Scan**. When interacting with the DIP framework, the users utilize the *scan* function. The files displayed by the DIP server are tagged with *QR Code tags*. After scanning an item of interest with the user's mobile phone, it is displayed on the DIP screen (if the accessibility has not been limited and privacy settings allow). By scanning a video file, the video file automatically is started on the public screen. In order to stop, the user has to scan a *quit tag*, located in the lower-left corner of the DIP screen, as seen in Figure 4.8(a). If scanning a text-file, only a preview version of the file is displayed on screen, to provide a short overview. If of any interest, the file can be *taken* or *cloned* by the user, for further investigation.

**Take**. With the *take* functionality, the last scanned and active item is *taken*. The item is downloaded to the mobile device and deleted from the DIP screen, making the item unavailable to other users.

**Clone**. Similar to the *take* functionality, but only downloads a copy to the user's mobile device, leaving the original item available to other users.

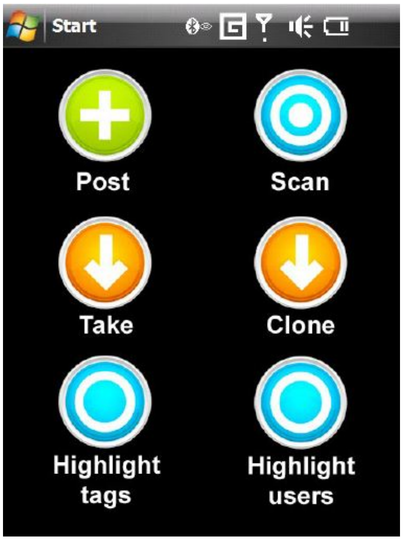



Figure 4.7: The Digital Interactive Pinboard (DIP) Windows Mobile GUI [TCO+10].

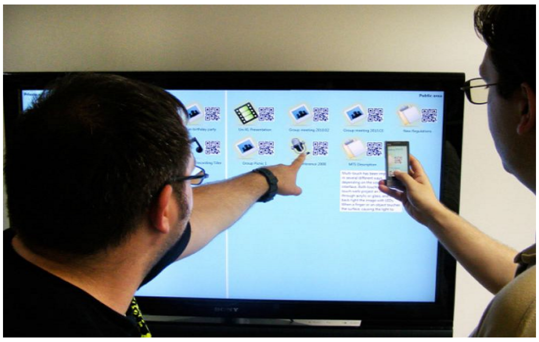
**Highlight tags**. By *highlighting* tags, the user can filter content, based on the tags the contributing users have provided with their shared items. The user can select tags to be highlighted, based on a list provided by the DIP server. After selecting the tags of interest and sending a query to the server, the server highlights and displays the items matching the selected tags.

**Highlight users**. The *highlight users* functionality provides a filtering option based on the registered users database. The functionality allows for the browsing of shared content by a specific user or users. The major benefit of this function is the possibility to detect if an user has enough rights to *take* or *clone* an item, since only accessible files will be displayed (for checking this, the user has to *highlight* his own account).

Interaction with the DIP framework and its public screen is intuitive. By utilizing *QR Code tags*, which have become very popular recently (e.g. in print media), users do not need to learn complex interaction gestures or have to struggle with a complex graphical user interface. Both server as well as client GUIs are clearly structured and provide for easily perceivable icons.

At a first glance. the DIP functionality seems to be limited, but by applying the *reduce* principle, all unnecessary functionality, providing no benefits to the user

(a) Server GUI.



(b) Scanning a tag.

Figure 4.8: The DIP prototype set up in a hot spot [TCO+10]. (a) The server GUI of the DIP prototype, based on a client-server model. (b) The public display, located in a *hot spot* (office environment), offers enough space in front of the screen to enable both face-to-face discussion as well as collaboration.

experience, has been disregarded in the DIP framework. Simplicity is a key to achieve enhanced usability.

By using the user's personal mobile phone (or tablet PC) and utilizing the mobile phone camera as an interaction modality, the advantage of being able to carry the interaction device is given; which also serves as the storage device, *stand of arms*.

The DIP approach also is highly scalable and versatile. It can be applied in various settings, basically everywhere, where information can be shared by a group of users.

**Choice: Bringing back self-determination to users - Social factors of public displays**

Besides from addressing technical issues like network traffic, caused by mass emails to all users of a work group or company (DIP therefore makes a contribution to reduce both Spam as well as network traffic), DIP also takes social aspects into consideration, like the paradigm shift of the *information society*, from traditional print media to digital media.

The DIP approach considers the fact, that information technology has become part of the *everyday culture & life*. Due to the *hot spot* location, DIP also serves as a meeting point for social interaction (conduce to work-life balance).

Furthermore the DIP framework provides for *time independent* access to information. Users have the *choice* when to check news on the public screen and they also can determine what information they think is important enough to be downloaded. There is no need to send out general information or announcements by email. DIP offers a valid approach to distribute information, e.g. in office environments.

### 4.4.2 Digital Interactive Public Pinboard - Exploiting mobile smart device interaction modalities for first responders

The client system of the **D**igital **I**nteractive **P**ublic **P**inboard (DIPP) prototype [OCM+12] is functional under Microsoft Windows Mobile and is implemented in Java. An updated version of the DIPP client now also ensures functionality under Android OS, offering increased versatility. Support for Apple iOS clients is under development.

The requirement for the connecting client devices is a WIFI interface. WIFI allows for a stable and uncomplicated direct connection to the DIPP server, which is also driving the public display.

Contrary to the original DIP approach, the DIPP framework does not rely on the mobile device camera as an interaction modality. After connecting the client to the server, the mobile phone's screen serves as a *secondary display*, also enabling multiple users to connect to the server and individually interact with the DIPP framework. The touch interface (or generally speaking: the mobile device itself) serves both as a secondary display and as an interaction input device.

Interaction functionality supported by the client:

**User registration**: An initial registration of the potential users (e.g. first responders, aid personnel, refugees, citizen) with the DIPP architecture is required, before being able to use the DIPP system. The registration also serves the purpose to share some basic information about profession (engineer, doctor, fire rescue etc.)and relevant skills (first aid, communications, languages etc.), in order to be able to contact that specific person or group. Single users or user groups can register. The information stored in a central database, locally. Simultaneously the information is automatically synchronized with other DIPP hotspots (requirement: a working internet/network connection).

**Displaying and downloading information**: Similar to the original DIP approach, the users are provided with the functionality to filter information, e.g. to display the nearest rescue shelter position. Important information can be downloaded to the mobile phone, e.g. maps with safe areas, basic supply positions (medical, food, water), contaminated areas, rendezvous points, rescue headquarters, areas already cleared by search & rescue teams etc.; DIPP supports various file types, ranging from video files, image files, as well as text files in order to provide additional information about local conditions (e.g. blocked roads), which are considered to be *mission critical*.

Tasks related to the skills of the registered user or the user group are highlighted on both the public screen as well as the mobile phone display, serving as a *secondary display*. By providing task suggestions (highlighting user specific tasks suiting the user's skills, deposited in the user profile upon registration), DIPP is increasing both efficiency and effectiveness of aid & rescue measures. Visual analysis is guided, improving performance and therefore improve response time. In addition this feature also serves as a security & safety feature, *hiding* dangerous tasks from people not having proper training to securely and safely perform the needed task, and therefore putting themselves in harm's way.

**Uploading information**: The DIPP architecture actively promotes user participation. Registered users have the ability to contribute to the DIPP system by uploading information. Like pinning pen & paper information to traditional billboards, users can interact with the DIPP architecture; digital content can be shared and is accessible for other users (with certain limitations, e.g. security and safety, based on skills). User can contribute geo-referenced files, in order to provide additional situation reports, in order to allow for judgement in order to initialize adequate measures in certain areas. New information is verified by authorized personnel only, thus maintain a quality standards of the posted information.

Mobile phone interaction is a qualified method of interacting with public display environments, especially in the field of disaster management. With minimal guid-

Figure 4.9: The Digital Interactive Public Pinboard for disaster management. The DIPP prototype [OCM+12].

ance users are able to interact with the DIPP architecture, utilizing their own, WIFI capable, mobile phones as interaction devices.

This has several advantages over other known approaches to allow for interaction with public screen, e.g. touch screens or information terminals with integrated keyboards and trackballs:

(a) the interaction device is known (since it is a personal device) and therefore does not need a training period, users feel comfortable.

(b) common mobile phones are literate of the functionality needed, in order to interact with the DIPP server (display & WIFI connectivity).

(c) a WIFI network can be set up easily, making this approach feasible for a disaster scenario.

(d) the interaction device serves as a secondary screen (dual screen approach), so it is not necessary to gather directly in front of the public display, still leaving the public display screen available to other users and providing recent information (e.g. new ticker).

(e) the secondary screen also allows for user group management, in order to provide sensitive or restricted information only to a specific user or a specific user group, designated by the file properties. The secondary screen (mobile phone display) serves as a private screen.

(f) the mobile phone interaction approach allows for multiple user interaction, same place, same time.

(g) the mobile phone serves as a storage device and therefore information can be directly exchanged (upload & download of files) and is ready to be used on the mobile device, like updated map material, contact information, tasks.

## 4.5 Interaction in Virtual Reality environments

Interaction within Virtual Reality environments pose challenges, especially when designing ways of user interaction. Both interaction devices as well as Graphical User Interfaces, have to be capable of meeting the needs of users. Traditional interaction devices, like keyboard & mouse, are not suitable for VR environments, since they limit users in their mobility within VR space, one of the major contributions of virtual environments.

The **V**irtual **R**eality **U**ser **I**nterface (VRUI) development library provides the basis for developments of applications in the field of Earth Sciences, Geology and Mechanical Engineering. VRUI also provides the GUI used in VRUI-based applications. This GUI basically is derived from traditional desktop GUIs, with over-boarding menu structures, containing text information. This is problematic, since readability of text in VR environments can be difficult, as well as browsing through a complicated menu structure, with a flightstick as interaction device, becomes a real challenge for users. Selecting a function out of the menu with extended sub-menu structures can be frustrating, because the pointer has to be navigated with the less precise flightstick.

In a desktop environment the menu structure can be accessed more easily, by using mouse interaction, with superior pointer precision. However, the precision of the flightstick in VR is inferior, so the selection of functions in VR is even more tedious.

(a) Tracked Flightstick.

(b) Tracked Glasses.

Figure 4.10: The *master user's* glasses and interaction device are tracked (FBK, University of Kaiserslautern, Germany). (a) The typical interaction device in CAVE environments: a flightstick. Also visible the spheres added for tracking the position of the flightstick. (b) Trackable glasses for the *master user*.

Since interaction is the connecting link between user and VR, therefore crucial for both the immersive experience as well as usability aspects, the interaction mechanics have to be improved.

The users working in the VR environment are equipped with a flightstick (compare Figure 4.10(a)) and glasses (as seen in Figure 4.10(b)). The main user (*master user*) is equipped with tracked glasses, so that the visualization is synchronized according to his head position. The interaction device, the flightstick, also is tracked by an electro-magnetic sensor field (e.g. *Flock of Birds*).

The informal evaluation (compare Chapter 3.4) proved, that navigation approaches in VR, using the flightstick, are considered intuitive, although a training period is needed in order to accustom with the rather new interaction mechanics in virtual space.

The major shortcoming identified (in terms of usability and the overall user experience), has been the Graphical User Interface, provided by the VRUI framework. A desktop GUI is transferred to Virtual Reality, neither considering the different user experience due to 3D perception capabilities, nor considering the interaction device with a considerably reduced precision, especially for menu selection tasks.

Therefore new concepts have been developed, in order to suit the user's needs and to provide for improved usability, considering both environment (VR), as well as interaction device (flightstick).

### Designing an User-Centered Graphical User Interface to enhance usability in VR

Since navigation with the flightstick has been rated good and intuitive, considering a more extended training period, the GUI certainly can enhance the overall user experience.

When thinking about an alternative GUI design, the following criteria have been taken into consideration:

(a) interaction device: designing the GUI with the least precise interaction device in mind, in order to assure usability & scalability on arbitrary display environments (VR: CAVE, dektop, PowerWall etc.).

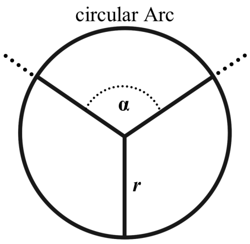
(b) designing a GUI utilizing the immersive capabilities of VR environments, adapting the GUI to 3D and human vision in 3D environments, thus maintaining 2D capabilities for 2D environments.

(c) improving user perception by using icons instead of textual menus; text is hard to read in VR, so menus should consider that fact and provide a solution. Icons are a straight forward alternative.

(d) since the *master user's* view also is tracked, simple gesture interaction can be utilized, e.g. to navigate through menu structures.

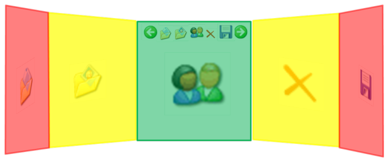
### Virtual Reality *ARC*

In order to provide an "easy-to-interact-with" GUI, a radial menu came to mind (compare Figure 4.11(b)). Based on a radial menu (revolver menu), a horizontal radial menu has been sketched, as seen in Figure 4.11(c). The *ARC* menu metaphor derives from a circular Arc geometry (compare 4.11(a)).




(a) Circular Arc.

(b) Radial menu design.



(c) Horizontal radial menu design.

Figure 4.11: Scalable menu structures for arbitrary display environments, in order to suit the scalability of the VRUI framework [Ole12]. (a) Circular Arc. (b) 2D radial menu. (c) Horizontal radial menu to utilize field of view in VR space.

When used in VR, the menu appears as an *ARC* around the user's head. Utilizing the *human field of view*, the menu can be structured in various parts.

Since human vision is divided into the two parts *binocular vision* and *monocular vision*, the *ARC* menu metaphor follows this given condition. *ARC* divides the menu into *perception zones*: the focus area (green) and the peripheral vision areas (yellow & red).

The *binocular vision* area usually consists out of the yellow and green areas. In order to create a focus area, a so called *work space* zone (compare Figure 4.12), the 120 degree field of view area (*binocular vision*) has been subdivided further, in order to make the menu more accessible and allow for navigation by head movement.

The *ARC* menu combines gesture-based interaction, by simple head movement (since the *master user's* head also is tracked) and flightstick interaction to bring up the menu and to confirm the menu selection.

By creating the *work space* zone, the user can access the active menu selection by *eye movement*, so there is no accidental slip in browsing the menu, when accessing the *work zone* (the binocular zone has been scaled down to the *work zone*, to make head movement obviate in the focus area).

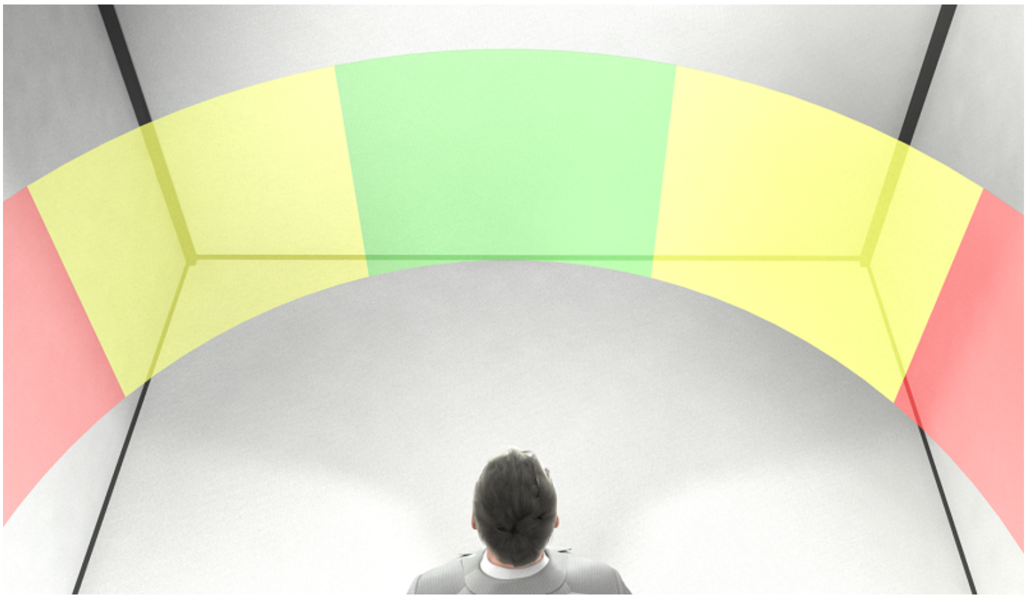


Figure 4.12: Concept of the *ARC* menu, inspired by the human field of view. The human vision is divided in *binocular vision* (green and yellow areas) and *monocular vision* (red areas). The *ARC* menu features an additional zone in the binocular zone, a *Focus* or *Work Space* zone (green) [Ole12].

By turning the *master user's* head left (compare Figure 4.13(a)), the menu point left of the selected item is shifted into the *work space* zone. If the user wants to select this menu entry, he can confirm with the flightstick by clicking the corresponding button. The same applies for selecting the adjacent menu option on the right (see Figure 4.13(c)). When looking forward, no gesture interaction is triggered, the *work space* zone is neutral, allowing for further selection with the flightstick.

The *work space* zone is defined by the user's head position at the time he brings up the *ARC* menu, by clicking the *menu button* on the flightstick.

Large menu icons take the less precise flightstick into consideration, and make further interaction more user friendly, compared to browsing through text-based menu entries.

The concept of the *ARC* menu can be easily transferred to desktop (2D display) environments. On a 2D display the users will have a simple *band menu*, without the perception zones and without gesture based selection.

(a) Head selection, left. (b) Neutral position. (c) Head selection, right.

Figure 4.13: Browsing the *ARC* menu by head movement. (a) Selecting left neighbouring menu option [Ole12]. (b) Neutral head position. Since the binocular area has been subdivided, the user can focus on the *work space*, accessing content by eye movement. (c) Selection of the right-hand menu option, by looking right.

After working with VRUI applications and conducting the evaluation, comparing both navigation and GUI interaction tasks, the enhancement of VRUI's GUI seemed to be a very pressing issue. In addition the CAVE user should also have the ability to change content from within the VR environment, in order to smoothen the work flow.

The design concept of *ARC* addresses these issues and offers a versatile and scalable solution to this pressing problem.

#### Virtual Reality: A platform for collaboration?

Virtual Reality environments, especially CAVEs, are suited as collaborative work environments, with limitations. In a CAVE only one user has control over the scene and can interact with content, in general. However, other users can join and act as spectators and engage in discussions, so collaboration is possible, to some extent.

Furthermore the VRUI framework allows for connecting with other CAVE or display environments, so that two or more users can collaborate with each others, from different places. The most pressing issue regarding collaboration using the same dataset is the avoidance of conflicts, when manipulating content. Therefore a real-time change management system is essential to ensure smooth collaboration environments.

Since VR environments are still a very costly option (both acquirement as well as maintenance) for creating collaborative environments, other solutions might be more suitable, depending on the intended task and if an immersive VR environment can offer additional benefits, other collaborative display environments can't offer, which are case-by-case decisions.

## 4.6 Summary

In this chapter interaction metaphors for three different display environments have been introduced. The introduced interaction metaphors ranged from implemented prototypes to conceptional design studies. The focus has been on improving usability and to create metaphors and interaction mechanics that suit the user's needs and also consider the particularities of display environment, visualization, user group and task.

Interaction is the crucial link between user and display environment & visualization. In order to create user-centered applications, which are meeting the requirements of usability, all aspects have to be considered and to be coordinated accordingly.

For tiled display environments an interaction metaphor using mobile phones and tag-based interaction has been presented, addressing issues like multiple user interaction in front of a large display, as well as privacy issues and user management for sensitive data.

Mobile phone interaction with public displays makes a contribution to show new ways in combining intuitive interaction methods and social components. By setting up public displays in *hot spot* locations, people can interact with both the display as well as with each other.

The *ARC* concept introduces a Graphical User Interface for Virtual Reality environments considering typical issues like text readability and the interaction device, offering less precision than a standard computer mouse. The *ARC* concept considers

| Display type | Multi-User | Collaboration (active) | Scalability |
|---|---|---|---|
| Tiled Display | yes | yes | yes |
| Public Display | yes | yes | yes |
| Virtual Reality (CAVE) | yes | master user | yes |

Table 4.1: Versatility of observed Display types regarding user interaction [Ole12].

these shortcomings and offers an elaborated alternative to the existing GUI.

### Collaborative work environments - A question of definition

Collaboration is enabled and facilitated by display environments. Some environments and the implemented applications support multiple users interacting, same time/same place. The examples of the tiled display as well as the public display environments show: both are feasible collaborative work environments.

With the further development in the field of mobile phones, mobile phones (smart phones, PDAs etc.) become more prevalent. Potential users bring their own interaction device and can connect & interact with various applications, if the application allows for. Since users can exploit their own mobile phone for interaction, training periods can be reduced, since an already known device is used for interaction tasks. Besides being serviceable as an interaction device, the user also can download information directly onto his hand-held device, providing additional value in regard to usability (no other external storage devices are needed).

Traditional CAVE setups allow collaboration with the limitation of one active user and additional spectators. For multiple users, being able to interact in one CAVE (same time/same place), the user tracking has to be improved. Nevertheless collaboration "conferences" are possible (same time/different place) (compare Table 4.1).

# Chapter 5

# VISUALIZATION APPROACHES ON ARBITRARY DISPLAY ENVIRONMENTS

## 5.1 Introduction

The term *visualization* has been defined by many scientists, each time slightly varying, depending on the field of application and the context it has been used.

The Oxford Dictionary defines *to visualize* in the following ways:

*"visualize*

*1. form a mental image of; imagine*

*2. make (something) visible to the eye"* [1]

Foley and Ribarsky [FR94] (p. 104) provide the following definition:

[1] http://oxforddictionaries.com

*"A useful definition of visualization might be the binding (or mapping) of data to representations that can be perceived. The types of bindings could be visual, auditory, tactile, etc., or a combination of these."*

The field of *Geovisualization* is described as an advanced discipline of cartography, enhanced through interactive content, following Rhyne et al. [RMD06].

Independent from the scientific branches, utilizing visualization techniques, visualization also is used in many other areas of application. In areas like architecture, industrial design, automotive design, mechanical engineering, modern computer-aided technologies, e.g. *computer-aided design* (CAD) and *computer-aided manufacturing* (CAM), are used to draft design studies and to visualize content. In the areas of architectural visualization or product design, the photo-realistic presentation visualizations for advertisement purposes are very popular, in order to provide pleasing previews of work-in-progress products to the stakeholders.

Visualization is well known to the broad public from a completely independent, non-scientific branch: the entertainment industry (*"Hollywood"*). Both motion picture industry and video game industry can be considered as the two branches which brought state-of-the-art visualization technology, albeit for entertainment purposes, to the "global public".

In order to utilize Virtual Globe applications like *Google Earth* and *Nasa World Wind* for visualization purposes, I introduce examples of *supportive visualization* approaches out of the the application fields of *Urban Planning* and *Disaster Management*.

## 5.2 State of the Art

The field of visualization is very broad and basically can be divided into the two major fields of *information visualization* and *scientific visualization*. For getting started the book *Information Visualization - Perception for Design* [War00] is providing a general introduction to the topic. In the following a basic overview of state of the art and related work out of the field visualization is provided.

A Top 10 ranking of information visualization problems is presented by Chen [Che05]. It is pointed out that not only usability aspects are unsolved, it is also exposed that user perception and also user knowledge are crucial factors when it comes to visualize content. With more and more interdisciplinary teams and increasing points of contact, these factors even gain importance.

The *fisheye view*, presented by Furnas [Fur86], [Fur99] addresses the problems users face when dealing with large datasets as well as large display environments: users can be overwhelmed by the abundance of information. With the *fisheye view* this problem is solved. The user's focus is narrowed, but the overview stays intact, remote areas are just displayed with less detail.

Robertson and Mackinlay argue that *fisheye views* as well as *magnification lenses* fail to preserve the global context view of users and therefore introduce the *document lens*. With their implementation user can stay in context while examining details [RM93]. In order to facilitate browsing and spotting relevant data in large data sets Deller et al. [DEB+07] compare pre-attentive visual features.

Shneiderman describes the *Visual Information-Seeking Mantra* as the starting point for designing GUIs and proposes a task (including, but not limited to overview, zoom, filter) by data type (one-, two-, three-dimensional data etc.) taxonomy [Shn96].

Al Gore [Gor98], in contrast, had a different focus on today's pressing challenges. He had the vision of a bigger concept, not dealing with solutions addressing only very specific challenges of visualization. He proposed the concept of a *Digital Earth*, as an interdisciplinary approach, combining and collecting geo-referenced information. Geovisualization can be utilized to address social problems (like monitoring crime rates and gang activity) and also serve as a negotiation tool to support decision making, just to provide two possible examples. A general overview of Geovisualization is provided by Kraak [Kra06].

The design of a visualization metaphor derived from real world experiences is described in the work of Skupin [Sku00]. The use of cartographic representations for visualizing non-geographic information is proposed. The approach shows that a suitable approach can be transformed from one field of application to another, sharing the benefits.

With *Many Eyes* Viégas et al. present an interesting approach to visualize content using the Web [VWvH+07]. Users are able to upload and share content on the *Many Eyes* platform, in order to create visualizations and foster collaborations between users. In this case visualizations are not only used as a intuitive tool to represent information, visualization also is used to start discussions, a social component often undervalued in the field of computer sciences.

Borning et al. introduce *UrbanSim* [BWF08], an application to simulate the impacts of planning decisions. Furthermore the tool can be seen as a decision support tool, making it possible to estimate impacts of planning decisions and simulate alternatives.

Eliasson and Upmanis [EU00] have done research in the field of urban microclimate. Their research deals with the question, how nocturnal airflow from Urban Parks can improve air quality and also microclimate. The results show, that green structures can be used to address inner city air ventilation problems, caused by building structures, therefore also making a contribution to the *Urban Heat Island* (UHI) problem. In the work of Chen and Wong [CW06] the problem of *Urban Heat Islands*, caused by a rapid population influx and the concomitant demand of new housing areas, is described. As a potential solution to improve inner city microclimate, green parks are investigated. Brazel et al. [BTG+09] also emphasize the use of green structures to countermeasure the negative effects of UHIs. Research insight is presented with the background of how to address the UHI problems with green structures in a desert environment, when there is water scarcity.

Andrienko and Andrienko [AA99] proposed the interactive maps to explore spatially referenced data. The system, *Descartes*, allows users to display data in a spatial context. Ai and Livingstone [AL09] pursue a similar goal, using *Google Earth*. Georegistered information is connected with the virtual globe, allowing the integration of multi-media data, like pictures or video streams, a goal also pursued by Kim et al. [KOLE09]. They augment aerial imagery with dynamic content.

In the field of emergency and disaster management applications Tai et al. [TLL09] introduce *TELES* (Taiwan Earthquake Loss Estimate System). The Google Earth application is able of simulating different scenarios and providing an estimation on, e.g., the damage caused to building structures. In the work of Guim et al. [GROM09] a distributed infrastructure for disaster support featuring Google Earth is described. A GIS for emergency management was introduced by Rauschert et al. [RAS+02]. Abed et al. [AHH08] also propose the usage of a web-based, open source GIS for emergency response. With *Sahana* [CSVdW07] an open source disaster management system is presented. Iizuka et al. [IIY11] introduce a real-time disaster mapping tool for university campuses. The application *Place Engine* allows the users to quickly navigate and determine their position on university campus. A vision for a disaster management system is introduced by Palen at al. [PAM+10]. The proposed system should support public participation processes during mass emergencies and large-scale disasters.

Isenburg and Shewchuk [IS09] introduce a tool kit enhancing the functionality of Google Earth dramatically: with the implemented tools large LIDAR (Light detection and ranging) datasets can be visualized using the Google Earth platform.

Wood et al. [WDSC07] critically reflect a Geovisualization mashup, also featuring Google Earth.

Koris et al. [KHO08] propose the usage of *Web 2.0* applications in order to provide innovative services to users. One service described by the authors using color coded push pins in Google Earth to visualize database information.

Houtkamp et al. [HCB09] conducted a visualization experiment by comparing three visualization approaches for visualizing current and future land use using the Google Earth application. Land use was visualized by color coded areas, icons and simple 3D-geometry. Although none of the approaches showed a significant improvement regarding user performance, users favoured the 3D representations.

Ying-jun et al. [YjCcJ09] provide a case study on how to exploit the functionality of Google Earth and the Keyhole Marker Language (KML) to design a cost-efficient Geographic Information System (GIS).

In [WRCS08], Wolfe et al. point out the challenges deriving from Geo-spatial Collaboration projects, like Google Earth. One of the core challenges is dealing with the validity of the contributed and therefore shared information. A discussion on how to deal with privacy issues, regarding data published within the Google Earth platform, is discussed in the work of Fleet and Williamson [FW09].

With *Crusta*, Bernardin et al. [BCK+11] present a Virtual Globe capable of real-time visualization of integrated high-resolution elevation models. It is tailored to be presented in VR environments, such as a CAVE.

Using laser scans for reconstructing real world environments is well known. In the work of Brenner [Bre05] various techniques to extract building structures from laser scans are reviewed. One of the challenges still is to provide aesthetically pleasing results, which are also suitable for non-expert users (point cloud data).

Gamba and Houshmand [GH00] have done research in the field of extracting building structures out of digital surface models (DSM). Most likely these models are also created by using aerial LIDAR (Light detection and ranging) data. Rottensteiner et al. [RTCK03] propose a method to automatically detect building structures using LIDAR and multi-spectral image data.

Kassner et al. [KKSB08] focus on the utilization of aerial LIDAR data to gain information on the solar potential of rooftops. Tolt et al. [TSA11] has a similar research focus, but not focusing on solar applications. A shadow detection method is introduced.

LIDAR data fused with color information from images is presented in the work of Mrstik and Kusevic [MK09]. The results are very promising, offering significantly more information than single coloured, standard point clouds.

Shadowing, one of the major problems of LIDAR data is addressed by Shih and Huang [SH09]. In their work an overlap approach for aerial LIDAR data is presented, to assure that point cloud density is sufficient.

In the work of Van der Zande et al. [VDZHJ+06] terrestrial LIDAR data is used to gather data on vertical tree structures.

With more and more complex data sets to be visualized the valid question of how much detail can be displayed as well as captured by the user's eye is brought up. Booker et al. are using tiled displays to visualize geo-temporal data, because both screen size and screen resolution of single display setups do not suit the needs when it comes to visualize large datasets [BBSN07].

Yost et al. [YN06], [YHN07] point out that there might be a shift in the limiting factors. Limiting factor for displaying large datasets always have been the limited resolution and limited size of displays. With scalable tiled displays these factor are gone and have been replaced by a new limiting factor: the limited perception of users. The question now coming into play is which resolution and which size is useful and can really help users in perceiving information.

## 5.3 Visualization approaches in the field of Urban Planning

In protracted *Urban Planning* processes more and more complex data has to be considered. Interdisciplinary teams of planners work with data, analysing and evaluating it in regard to planning specifications and regulations. Considering the interdisciplinary teams innovative visualization techniques and visualization tools can improve the efficiency of working with multi-dimensional data. User perception is supported by visualizations, emphasizing important features, thus making it easier to find correlations in the underlying data.

Unlike in the field of *Architecture*, where visualization approaches mainly are used for photo-realistic renderings (compare Maxwell Render [2]) and presentation purposes, the focus of *Urban Planning* is on utilizing visualization to convey complex information. The to be considered data is complex and visualization techniques can support planners as well as the general public to increase efficiency during planning processes. *Public Participation* has become an integral and active component of planning processes. The work of Kwartler [Kwa06] describes the effects and benefits of involving the general public in early stages of planning processes.

[2] http://www.maxwellrender.com/

In many building code laws, public participation already is recorded. Therefore it is essential to provide understandable representations of important data. But not only the participation aspects provide impulses for user friendly allocation of information, also new forms of *e-Governance* and public information systems demand new ways of transporting information to the general public. The dictums one has to keep in mind are transparency, comprehensibility and clarity.

Virtual globe applications are used to convey rather complex information to the public. My contribution to the field of visualization are reproducible approaches, using commonly available software, in order to minimize expenses, a crucial factor for smaller communities on tight budget. In addition, my visualization approaches convey information in a reliable way, geo-referenced, considering diverse groups of users, enabling them to access information fast and intuitive.

### 5.3.1 Google Earth as a planning support tool

Virtual globes, like *Google Earth* [3] and *NASA World Wind* [4], have become very popular in the visualization community. They offer the advantage of being well known by a large group of users, which is enabling users to create innovative content in a very user-friendly way, share content and exchange thoughts. With Virtual Globes and their easy customization possibilities, the *Digital Earth* vision of Al Gore [Gor98] is within reach.

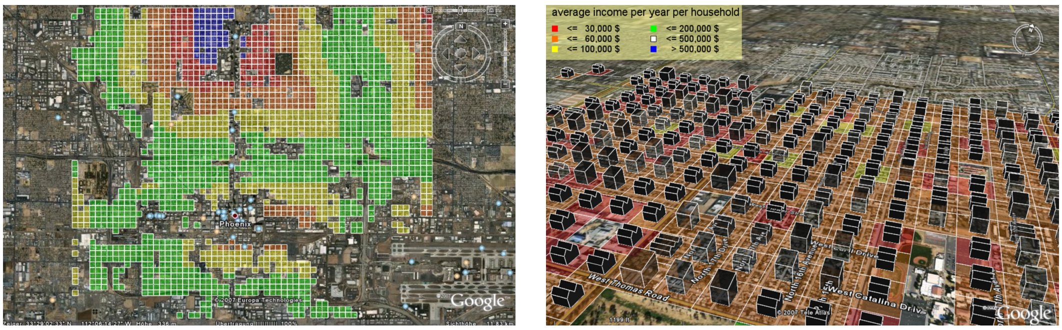
The Virtual Globe application *Google Earth* recently gained much popularity in the field of urban and spatial planning. The setup of *Google Earth* is user friendly, own content can be created easily, making it a convenient planning support tool. The main advantage of *Google Earth* is the ability to dynamically and interactively explore content online, without being bound to a fixed, static location. By the option to access the available geo-data and adding own content (e.g. superimposing satellite imagery with geometry or color coding), and in this way creating a visual synthesis, the amount of public available geo-information increases, according to the number of contributors.

[3] http://www.google.com/earth/index.html
[4] http://worldwind.arc.nasa.gov/java/

The wide variety of the community, contributing to Google Earth, is one core point of success. People are motivated to grant access to their visualizations and datasets, sharing and exchanging information. Google Earth has become one of the most popular virtual globe applications, because of the usability, making it possible to extend functionality to specific needs, thus becoming an easy-to-use visualization platform, e.g. for planning-related content. Furthermore communication is stimulated (active participation in creating content) and therefore collaborative work also is facilitated.

#### 5.3.1.1 Visualization of planning relevant databases

During planning processes diverse information has to be considered, in order to come to a planning decision ("finding consensus). Census data tracks provide information, which is of relevance for planning decisions. However, the information is deposited in spreadsheets, without spatial connection, making the assessment of the information cumbersome and complicated.




(a) Distance grid cell to highway entrance. (b) Income per grid cell (predicted building type geometry layer enabled).

Figure 5.1: Census information visualized within Google Earth [MGH+09]. (a) The color coding is showing the distance to the nearest highway entrance, allowing conclusions, when compared with the income situation. (b) Average household income per grid cell is visualized using color coded grids. The legend explains the color coding. The visualization within Google Earth offers an intuitive approach of visualizing geo-referenced data.

Google Earth is used to visualize multi-dimensional databases in order to provide *planning & decision support* [MGH+09]. Multi-dimensional data from a geodatabase is visually encoded as abstract and scalable 3D geometries. The data attributes are mapped to different visual variables of geometries, e.g., color, transparency, and geometric form. Geometries range from simple boxes and polygons to complex glyphs, such as 3D polygonal representations of typical building types, used to represent the major building type in a certain area.

This visually encoded information is superimposed on top of Google Earth aerial photographs, providing a spatial synthesis of abstract representations of geo-referenced statistical data (e.g. census data) in a real world context. By doing so, abstract data from spreadsheets with no spatial reference is represented in a geo-spatial context, enabling enhanced judgement and providing decision support. Comparison of data is easier and data mining is enabled, planners can compare neighbourhoods directly and utilize the findings in planning decisions. The synthesis of Google Earth and multi-dimensional databases allow for *visual analysis* of databases. Visual analysis is supported by the ability to combine different layers of information, increasing both flexibility and user friendly work flow.

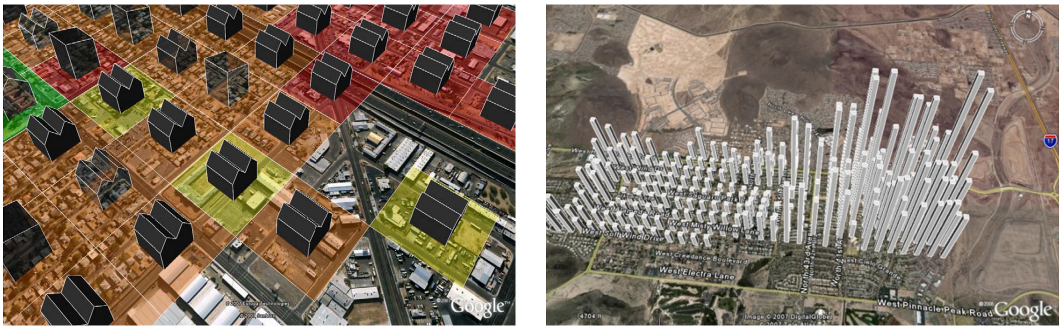
A simple but effective way to visualize content is color coding. Grid cells are color coded for fast visual perception (Figures 5.1(a), 5.1(b)).

By combining color coding with simple geometric representations, comparison of data and drawing conclusions on how this data is related to each other, becomes feasible. Therefore an interpretation of data is made more convenient and efficient.

Figures 5.2(a) and 5.2(b) show simplified geometries to support planners in perceiving information. By enabling the layers of *predicted building types* and *average income* the correlation of building type and income situation in a certain grid cell (representing neighbourhoods) becomes clear.

Having complex planning processes in mind and the diversity of involved actors, a straight forward visualization approach, suitable for people with various backgrounds and from different professional fields, is a logical consequence to enable discussions on an equal footing, in order to find consensus.

The Google Earth database visualization approach is extending the already existing possibilities of color coded 2D representations, known from traditional *Geographic Information Systems* (GIS), with 3D representation capabilities. By enabling a more user friendly access to information, without the need of long training periods, complex data is visualized and the therein encoded information is conveyed in an user friendly and intuitive way.



(a) Predicted building types. (b) Population density per grid cell.

Figure 5.2: Census information visualized within Google Earth [MGH+09]. (a) Simplified geometric building representations are used to visualize calculated, simulated predicted building types per grid cell. (b) Population density is visualized by intuitive bars. A comparison from grid cell to grid cell is more easy and intuitive, because in Census track the geo-referencing is not given.

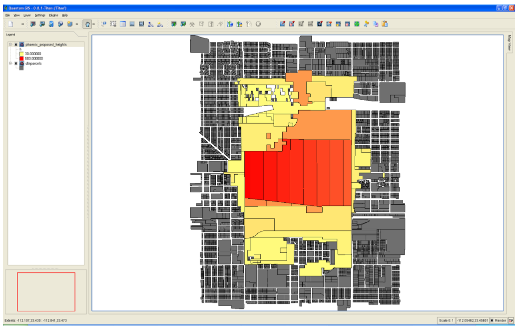
### Visualization within Google Earth

The multi-dimensional data is stored in a *PostgreSQL* geodatabase. The data (e.g. census data, demographic information) then is encoded to geometric representations (e.g. polygons covering a certain grid cell, boxes, simplified building geometries) using *PHP scripts*. The *Keyhole Markup Language* (KML) is used to visualize the content within Google Earth, according to the calculated attributes.

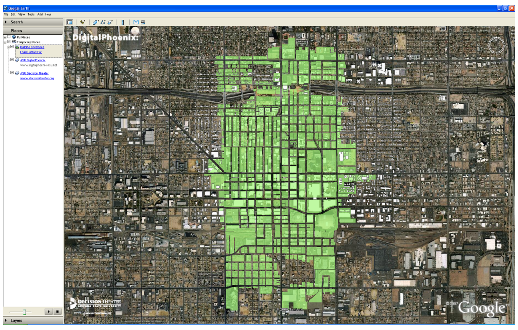
#### 5.3.1.2 Visualization of policies - Building Code violations

Sitkowski and Ohm [SO04] provide a brief introduction to form-based code. Form-based code is a design-based land-use regulation tool. It provides a basic guideline on how buildings have to look like, similar to German building code law.

This second Google Earth application is based on a framework that has been developed in the Digital Phoenix Project at Arizona State University, AZ, U.S.A. [MPOH08].



(a) QuantumGIS.



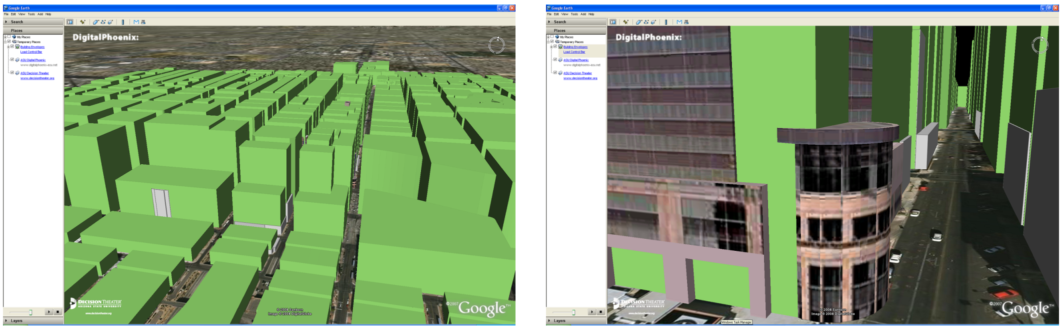
(b) Top view Google Earth.

Figure 5.3: Building code policies can be adjusted in QuantumGIS, an open source GIS program [MPOH08]. (a) QuantumGIS interface, QuantumGIS Parcels and Proposed Heights. (b) Additional top view within Google Earth.

This application generates 3D bounding volumes resulting from Form-based Code (FBC) regulations, stored in a geodatabase, for display in Google Earth. FBC is a land development regulatory tool which focuses on the physical layout of the built environment, in particular, the form of buildings and the arrangement of streets and sidewalks. The 3D visual representations of building form parameters, resulting from FBC regulations, are superimposed on Google Earth satellite imagery. By doing so, abstract FBC regulations are showcased in a real context, thus making the regulations more comprehensible.

The visualization gives a visual representation of abstract building code terminology, explaining complex building code laws to stakeholders by providing an illustration of legislative texts within *Goggle Earth*. Stakeholders are supported in getting a better understanding of recent as well as future developments and the impacts of FBC regulations.

Traditional 2D GIS approaches (compare Figure 5.3(a))lack the ability to provide 3D representations of information. Therefore the spatial impression of *building mass* (Figure 5.4(a)) can't be provided by traditional 2D GIS approaches.




(a) 3D visualization within Google Earth.   (b) Comparison adjustments of building code law with existing buildings..

Figure 5.4: Building code policies can be adjusted in QuantumGIS, an open source GIS program. The output is given within Google Earth, as a 3D representation [MPOH08]. (a) Planning Area showing the volumes with buildings. The planner can estimate the building masses and judge aesthetic value of new developments. (b) Existing buildings that do not fulfil the new building code are visualized. The existing buildings that violate the new building code are sticking out of the green hull, which is representing the maximum permissible building size.

As shown in Figure 5.4(b) users can immediately identify building code violations. In this example a *building hull* (the green box) represents the maximum permitted building size, according to Form-based code regulations for the viewed area. The existing building, in this case, violates the Form-based code regulations, since it is larger than the building hull. The graphical representation of building code regulations support users in understanding information; a visual representation can be conveyed more efficiently and more effectively than legislative texts. With visualization approaches, suiting both tasks and users, the usability can be improved.

### The policy visualization framework

The framework is designed as a *client-server* application (compare Figure 5.5).

The policy related datasets, containing the underlying building code regulations, are stored in a *PostgreSQL* database, which features a geo-spatial *PostGIS* extension. The database is connected to *QuantumGIS*, in order to enable users to analyse and manipulate data.

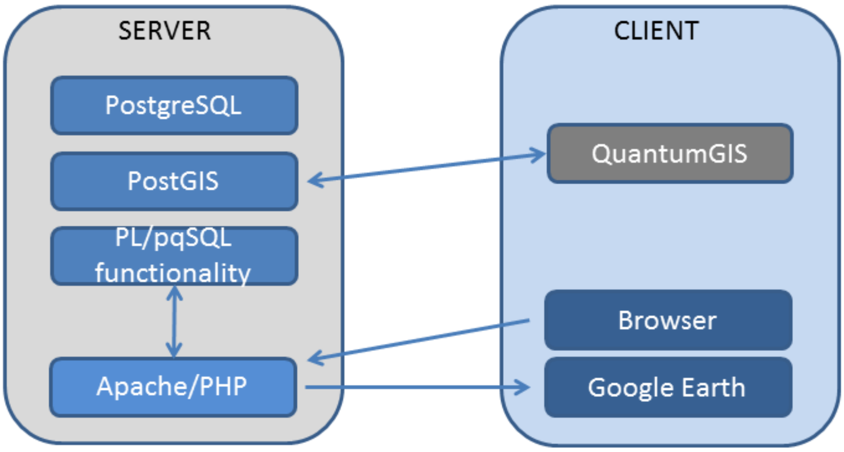



Figure 5.5: Form-based Code visualization framework [MPOH08].

Simple bounding volumes (*building hulls*) are calculated, based on the regulations stored in the geodatabase. On the server side a *PHP* script encodes the geometries and streams them as *KML-files* to *Google Earth*.

*QuantumGIS* enables users to edit and manipulate *PostGIS* data and change regulations to check out planning alternatives.

By combining traditional GIS functionality with 3D visualization support, urban planners are able to work with known tools (GIS), extended with Google Earth connectivity as an additional feature, enabling the ability to receive visual feedback and therefore receive an early impression on the planning decisions impact. In this way the visual representation of legislative texts allows for an enhanced estimation of the building mass of new developments and the thereof urban planning related impacts, e.g. the shadowing of adjoining buildings and properties.

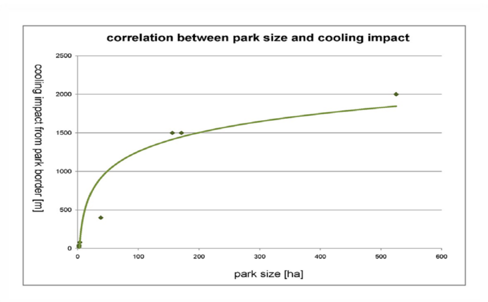
As a result, both planning as well as public participation, are more intuitive, since complex building code policies are visualized in a comprehensible way and therefore offer a common basis for discussion for all stakeholders, not only expert users.

In addition, by the careful combination of Google Earth and the open source GIS application (QuantumGIS), this approach even becomes reproducible and usable by communities, not being equipped with a big budget.

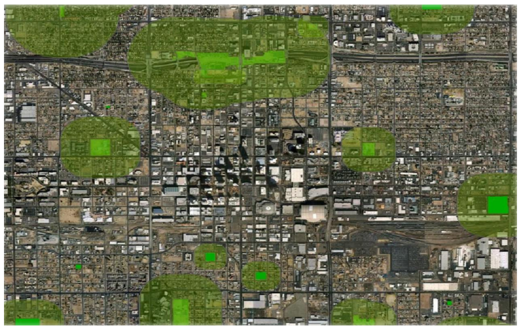
#### 5.3.1.3 Visualization of Urban Heat Islands (UHI)

**U**rban **h**eat **i**slands (UHI) have become major adverse environmental impacts, resulting from man-made building structures.

The phenomena of urban heat islands is caused by thermal absorption of man made structures during daytime, mainly in warm, arid areas. Under normal circumstances, cooling processes would start during night. The problem of UHIs is, that the high temperatures are preserved by the building structures during night, so that there is no tangible cooling process. The urban climate changes, with negative effects for flora and fauna, as well as humans.




(a) Correlation park size and cooling impact.



(b) Cooling impact related to park size.

Figure 5.6: The correlation of park size (green structures) and cooling impact is visualized in Google Earth in order to address the Urban Heat Island (UHI) problem [MOH09]. (a) Correlation of park size and cooling impact. (b) Visualization within Google Earth showing the cooling impact according to calculations.

With regard to sustainability the effects of UHIs are negative, e.g. air conditioning has to work during both daytime and night-time, increasing the energy consumption (electricity) and also cause further adverse effects to natural resources (e.g. water consumption, for watering and maintaining green structures). Besides negative ecological effects also negative economic effects are caused: UHIs are a cost factor in both the public sector, as well as the private sector.

However the negative effects caused by building structures can be addressed by urban planning decisions and the thoughtful integration of green structures, integrated into the build environment. The urban climate benefits from green structures and their impact is not only of local relevance [CW06]. Green structures can influence the urban climate nearby and be an effective countermeasure to the adverse environmental impacts of Urban heat islands.

In order to provide planning support, *Google Earth* is utilized as a climate mapping tool [MOH09] for sustainable planning. As a countermeasure to UHIs, Saito et al. [SIK90] propose *Park Cool Islands* (PCIs), harnessing the *oasis effect*. Upmanis et al. [UEL98] validated that the oasis effects of parks are not locally restricted to the park size, positive cooling effects extend beyond park size, influencing urban climate and urban cooling processes. The correlation of park size and cooling impact is shown in Figure 5.6(a).

A basic calculation provides an estimate of cooling effects in nearby urban areas. Since the formula used for the calculation disregards factors like wind speed and wind direction, urban structures and urban density, the visualized results have to be looked upon as approximate values. Based on the logarithmic relationship of park size and cooling impact, the resulting graph function is used to calculate *impact zones* of existing parks in Phoenix, AZ, U.S.A., using the application *ArcGIS*. The resulting *shapefile* then is exported to *Google Earth*, enabling users to dynamically explore the data.

As a visualization method for the cooling impact within the *Google Earth* application, color coding and transparency are used. Existing green structures are shown with green color coding, the resulting *oasis effects*, based on the simplified calculations, are shown as semi-transparent *impact zones* (compare Figure 5.6(b)).

The visualization gives a first impression on how green structures affect the local urban climate and therefore planners can superimpose this "Green structure and cooling impact layer" with a layer showing critical night-time heating areas (Urban heat islands), in order to initiate counter measures and to consider green structures in planning concepts.

### 5.3.2 Visualization using figurative visualization metaphors

Air Quality has become a well-known catchphrase since the public awareness has been raised by particulate matter and carbon dioxide discussions and therefore is monitored in nearly every city. By this approach a high volume of measurement data is produced, based on the different pollutants and multiple measurements per day at various measurement locations throughout the cities. The gathered measurement data is available to the public online, presented as numerical series, making accessibility for non-experienced users difficult.

The challenge is improving perception of complex data, in general; to enable both the public and the different stakeholders working with the data to understand the provided information without a long training period.

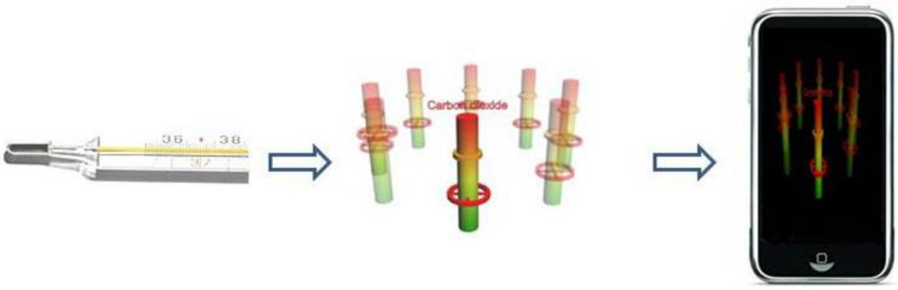


Figure 5.7: Fever. A figurative metaphor to visualize air pollution [OCT$^{+}$10].

On the one hand it is important to provide the data to the public as a basic and unfiltered information resource; on the other hand the data is crucial to planners as a basis for planning decisions, for example when working in the field of traffic abatement and environmental zones. It is substantive that the involved actors, even with a different standard of knowledge, can access and understand the data easily. This can be achieved by using suitable visualization techniques, tailored to suit the task.

*Fever* [OCT+10] is a visualization metaphor for visualizing air pollutants. The *Fever* metaphor gives support to the users by improving the perception of important information in a very natural and intuitive way. In this manner exploring the measurement data becomes more user friendly. By using *Fever* both work flow and user satisfaction is enhanced. Instead of browsing through numerical series, the user can directly access each pollutant, visualized as a virtual mercury thermometer representation, as seen in Figure 5.7. The user can rapidly recognize, if limit values are reached. Although not intended for the use with large high resolution displays, *Fever* is also an example of rehashing data to provide a more intuitive and user friendly visualization, for example as an information application suitable for mobile devices.

Th design of the *Fever* metaphor is derived from traditional mercury based clinical thermometers. These clinical thermometers are well known and feature a scale with a well visible mark for critical body temperature: if this mark is reached by the mercury inside the small glass pipe, then everybody knows: fever, without needing to know at which temperature it is considered fever. A simple mark helps the user in perceiving this information in an easy and fast way.

This metaphor is used to re-implemented an air quality visualization. Simple geometric forms (columns), color coded by a gradient from green to red, with a significant mark (bulge in the column geometry), are used. If a certain mark for a specific element of air is reached (the limit value), the user can spot, at first glance. The actual air quality is visualized by a red ring, floating up and down the column. Users easily can perceive if everything is below critical limit values.

## 5.4 Visualization approaches for a Disaster and Crisis management system

When visualizing natural disasters and related events for *Disaster and Crisis management*, the focus of visualization is on *comprehensibility*. First responders, relief personnel as well as the general public have to be able to quickly access and understand important information. Complex coherences have to be simplified but still capable of conveying information. In an ideal case, users can understand the displayed information without long training periods or the need to consult a manual.

A general guideline for medical support during emergency scenarios is provided in [fBuK10]. Having this guideline in mind, basic functionality is integrated in the prototype application. For comprehensibility issues I introduce simplified icons to convey the necessary information to the users (first responders, aid personnel etc.).

The **D**igital **I**nteractive **P**ublic **P**inboard (DIPP) prototype for Disaster and Crisis management evolves around an earthquake scenario [OCM+12].

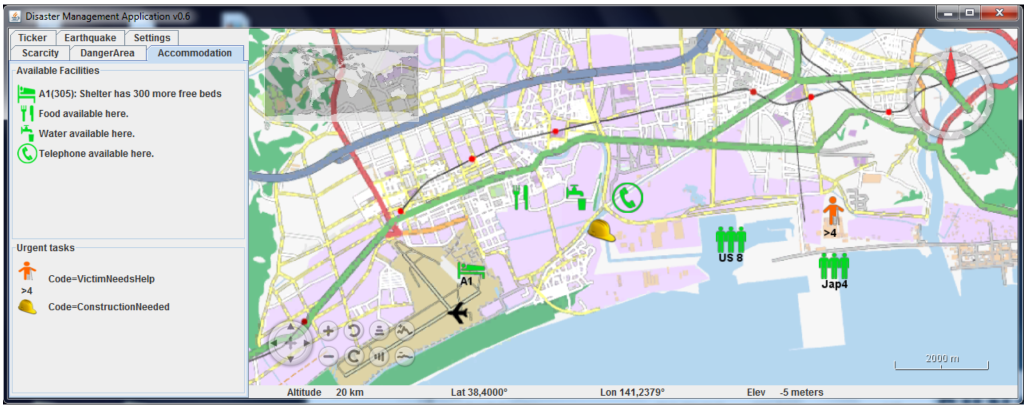


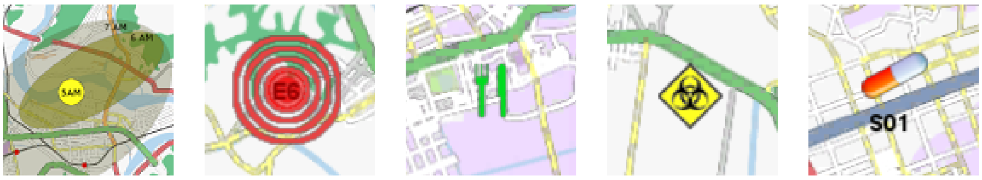

Figure 5.8: The DIPP Prototype. Accomodation [OCM+12].

For visualizing earthquakes within the NASA World Wind environment, GeoRSS is used to obtain recent data.

Concentric circles represent the location of earthquakes on the earth surface (not the *epicenter*). The number of circle rings also provide information on the magnitude, according to the *Richter scale*. A flashing symbol indicates the most recent earthquake/aftershock, catching the attention of the user , as seen in Figure 5.9(b) (providing *visual guidance*).

Additionally, the positions of emergency personnel in the field is visualized, in order to be able to coordinate and monitor search & rescue teams, for example (compare Figure 5.10(c)).

Details-on-demand can be accessed using the left hand information bar, providing more in-depth information, if needed (Figure 5.8) or news ticker functionality (Figure 5.11).




(a) Danger Forecast. (b) Earthquake. (c) Food. (d) Hazard. (e) Medicine.

Figure 5.9: Icons used in the disaster management prototype for Digital Interactive Public Pinboards, utilized in hot spots. The icons are comprehensible and also feature color coding (green: situation OK, orange/red: there is a problem, e.g. shortage on food, medicine) [OCM$^+$12]. (a) Danger Forecast. (b) Earthquake icon. The number of rings also shows the magnitude according to Richter scale. (c) Food supplies/Food supplies needed. (d) Other Hazards (besides the earthquake icon). Additional dangers can be marked and geo-referenced. (e) Icon displaying medicine supplies or shortage, depending on color coding.

### Where to go?

Arriving relief personnel has to struggle with very basic questions, like accommodation, especially if the personnel is not part of a major relief organization.

In case of a disaster event, like *Tohoku*, Japan, local emergency personnel most likely has no capacities to take care of arriving international relief personnel, since they already are working full capacity to provide help and guidance for the local population, affected by the disaster.

The DIPP prototype provides accommodation help: DIPP shares information about accommodation availabilities by using easy to understand icons and color coding. The green symbols indicate vacancies, the red symbols indicate all slots are already occupied. DIPP chooses accommodation locations based on the data, the users have entered upon registration. If an electrical engineer has registered and is looking for a place to sleep, the DIPP system will indicate camps, where the user's specific field of expertise is of use for the community.


(a) Not responding. (b) Shelter. (c) Team. (d) Telephone. (e) Water.

Figure 5.10: Additional icons used in the disaster management prototype for Digital Interactive Public Pinboards, utilized in hot spots. The icons are comprehensible and also feature color coding (green: situation OK, orange/red: there is a problem, e.g. shortage on food, medicine) [OCM+12]. (a) The not responding icon shows the last known position of a first responder, after he did not respond. Search parties can be send to check what is going on. (b) Shelter possibilities, providing information on accommodation for both first responders, as well as citizens. (c) Team icon. (d) Hot spot or location where updates and information can be accessed. (e) Icon displaying water supplies or shortage, depending on color coding.

### Managing goods.

A *vigilance* system allocates information about potential bottlenecks of essential goods (medicine, food, drinking water) as well as important tasks. For visual consistency the color coding scheme is also carried on with the essential goods icons.

The status of essential goods is visualized by the use of easily perceivable and accessible icons. Similar to earthquakes, urgent needs are visualized by flashing symbols, drawing the user's attention (visual guidance). Utilizing symbols/icons on a map environment has several advantages: the user can perceive what is needed and immediately is provided with the additional information of the location.

### Hazards.

Besides the scenario related earthquake visualization, other hazards also can be displayed (compare Figure 5.9(a)). Potential spatial impacts of hazards are visualized using transparency (gas leak, chemical spill, contamination area). The relief personnel is able to estimate risks and can prepare themselves by wearing adequate protective clothing, before entering hazardous areas.

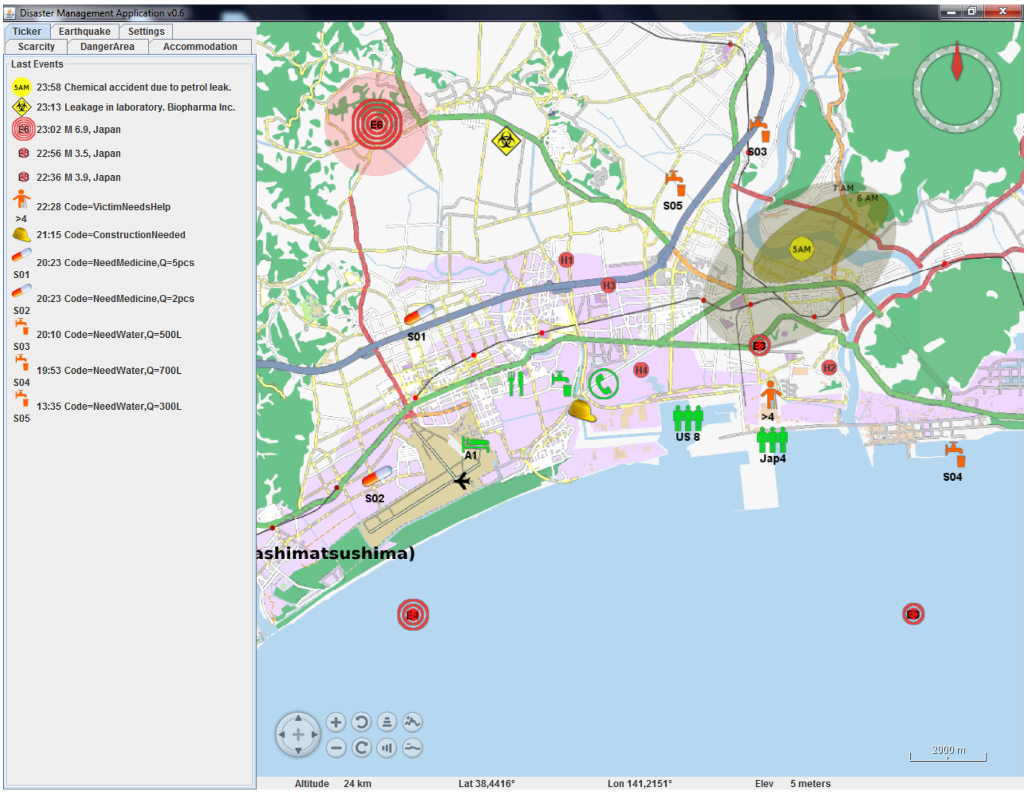



Figure 5.11: Ticker function allows news feed in real time [OCM+12].

**News ticker.**

The news ticker function (Figure 5.11) collects the information of all layers and displays them in a chronological order as *news events*, most recent updates on top (sorting the information).

By selecting specific layers, the user can filter information, so that he only sees information of interest, in order to counteract *information overload* and *information cluttering*.

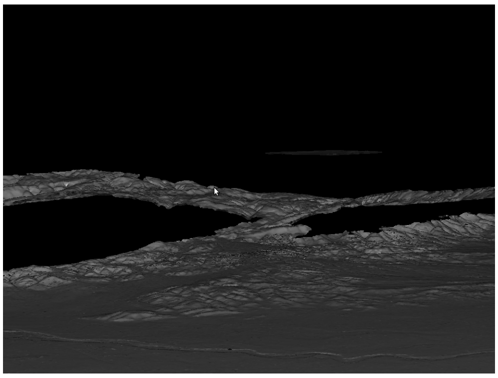
The visualization approaches, implemented in the DIPP prototype, focus on conveying information in a fast and reliable way, considering diverse user groups. By using simplified icons, color coding in combination with a map as a basis of information visualization, rather complex information can be visualized in an efficient and effective way, to ensure comprehensibility to a variety of users.

## 5.5 Visualization in Virtual Reality (VR) environments

**LI**ght **D**etection **A**nd **R**anging (LIDAR) data is used in various fields of application, e.g. civil engineering, earth sciences and geology. The methods for acquiring LIDAR data can be categorized into two categories: aerial based LIDAR data, captured by planes or drones and terrestrial based LIDAR data, captured from the ground. Generally speaking the latter one offers a higher resolution.

In the field of geology and earth sciences the acquisition of terrestrial LIDAR data offers the advantage of being able to capture very high resolution data, for documentation and analysis (e.g. earth quake research, fault lines). The terrestrial laser scanners are very expensive and sensitive, therefore time in the field is precious.

(a) LIDAR point cloud.



(b) LIDAR shading.

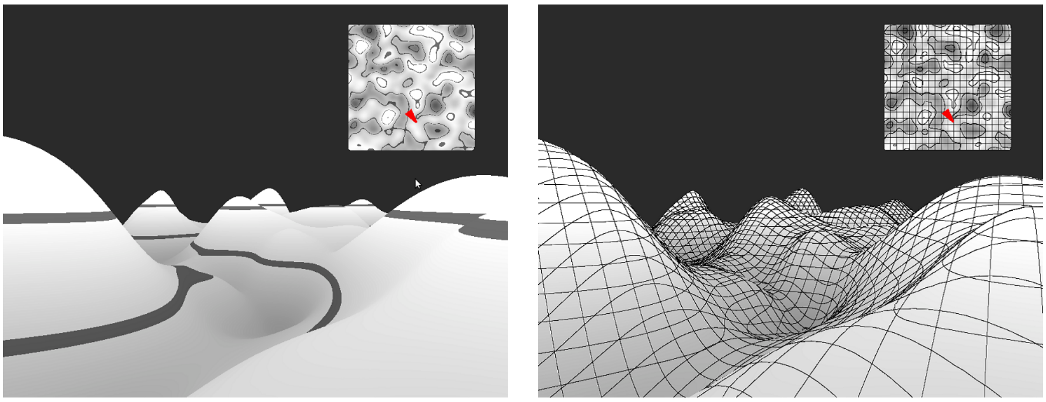
Figure 5.12: Aerial LIDAR data visualized in the LIDAR simulation tool for the VRUI middleware. (a) Aerial LIDAR data, point cloud. Perception is not that pleasing, especially in VR. (b) Dataset using shading for better perception and reasoning.

Setting up the terrestrial laser scanners in the field is a delicate and time consuming task, in order to avoid both *shadowing* as well as *oversampling*.

The *shadowing* problem appears, if objects block the laser beam and no sampling of the area behind the object can be acquired. The location of the scanner is crucial for satisfying results. Shadowing results in fragmentary point cloud datasets, oversampling results in overhead.

In order to improve the work flow in the field, a simulation tool can be used to prepare field trips and the setup of terrestrial based laser scanners. Since aerial LIDAR data is widely available, it is used to simulate terrestrial LIDAR scans in the VR capable tool. Users can simulate terrestrial laser scans and therefore determine the optimal laser scanner position on-site, prior to the field work. In this way, field trips can be more efficient and effective.

In a first step the aerial LIDAR data has to be rehashed [Amr12]. Base data, point cloud data (compare Figure 5.12(a)) offers poor perception quality, especially when working in a VR environment. A basic shading (Figure 5.12(b))is applied, in order to improve perception and to provide a better impression of the surface, to the user.



(a) Testing shaders: Height lines.

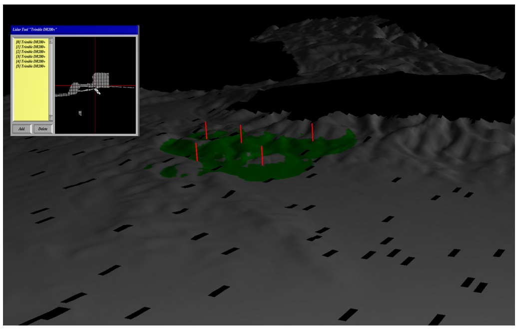
(b) Testing shaders: Grid cells.

Figure 5.13: Testing different shaders to make the LIDAR surface more catchy and enhance user perception, especially in CAVE and VR environments [Amr12]. (a) Height line shader applied to aerial LIDAR data. (b) Grid cell shader applied to aerial LIDAR data.

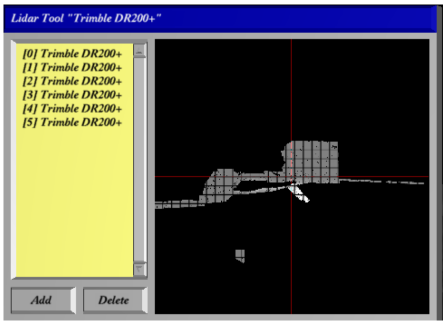
During implementation various shader approaches have been tested, in order to determine which shader enhances user perception in a VR environment. A *height line shader* was applied to the LIDAR surface (Figure 5.13(a)), as well as a *grid cell shader* (Figure 5.13(b)). However, both approaches have been rated less promising (*restless patterns*).

Simplified poles represent the *virtual terrestrial laser scanners* within the tool. They can be regarded as cameras, with a *view frustum* determined by the specifications of terrestrial laser scanner manufacturers. In order to provide an easy-to-use interface, the users can select different laser scanners, populated with preset data (e.g. view frustum, height of scanner). Additional laser scanners can be populated with ease, to ensure flexibility and scalability.

Users are able to virtually explore the aerial LIDAR dataset (rehashed and shaded in order to allow calculations), determine the area of interest and start positioning the virtual laser scanners (poles), as seen in Figure 5.14(a). The menu, pictured in Figure 5.14(b), is broken down to the basic functionality to ensure ease-of-use and also to accommodate the VR environment and the thereof resulting less precise interaction device (flightstick). However, the user experience can be enhanced by improving the traditional menu structure (compare Chapter 4.5).



(a) The prototype tool.




(b) Prototype menu and additional 2D map view.

Figure 5.14: The LIDAR simulation tool. A prototype [Amr12]. (a) The LIDAR simulation tool prototype, based on the VRUI middleware. Virtual terrestrial LIDAR scanners set on aerial acquired LIDAR data. Green area shows coverage of terrestrial LIDAR scanner, areas not green are affected by shadowing. (b) The LIDAR simulation tool prototype menu. There are presets for the most popular terrestrial LIDAR scanners. In this example the data of the Trimble DR 200+ is used for simulating the scans in VR. An additional 2D map view enhances user orientation.

The GUI also provides an additional 2D map function to the user, to support orientation, when navigating in the VR environment.

After setting up the first virtual scanner, a visual feedback (green) indicates the "covered" surface area. The user can determine how the scanners have to be set up, in order to achieve an optimal coverage, to avoid the undesirable *shadowing* & *oversampling* areas.

## 5.6 Summary

Visualizations have to be *accessible* & *comprehensible*. Information has to be conveyed by the visualization approach, ensuring fast assessment by the users.

In the area of urban planning, stakeholders have to deal with an enormous amount of information, composed out of different areas of responsibility (e.g. social concerns, ecological concerns, economical concerns, building code laws).

The important task when visualizing information is, to bridge the gap between enhancing comprehensibility (by simplifying) and loss of information (*Simplicity, KISS*).

The introduced *Google Earth* mashups prove, that Google's virtual globe application can be utilized to perform as a comprehensive planning tool for public participation, decision support and planning support. The Google Earth application can be used as a geo-analytically tool, with visualization capabilities.

Complex information, often only available in abstruse tables, can be visualized in a convenient and user friendly way, and represented within the virtual globe platform, geo-referenced. Since *Google Earth* is freely accessible over the Internet, it is also a cost-efficient option for small communities, with limited budget [OTM+09]. Attributable to the ease-of-use, the functionality can be customized or extended easily, in order to suit individual scenarios and user necessities.

In the field of disaster & crisis management, the fast, clear and reliable comprehensibility of information is crucial.

The DIPP prototype provides a clear and intuitive visualization approach, to effectively convey relevant data. In this case, the NASA World Wind framework is used as a basis, to geo-reference data (information, relevant to aid personnel), as a visualization platform. First responders have to access information and process the provided information fast and decide on further actions or coordinate measures. The visualization method, using icons and color coding on a map, is both efficient and effective to suit the requirements of foreign aid personnel.

Visualization requirements of data for virtual environments (e.g. CAVEs) are slightly different. The majority of users is used to 2D environments, therefore orientation in VR space can be tricky. Therefore the visualization as well as the GUI should provide user support, in order to mitigate this issue. In the example presented, the shader with its shadow calculations improves user perception of the LIDAR surface. Tests revealed, navigation using a surface is more convenient than navigation through point cloud data *mist* in VR. A simplified menu (GUI) counteracts information overload and also takes the VR interaction device into consideration, by reducing unnecessary functionality.

When visualizing data, not only the targeted user group has to be considered, also the display type (size & resolution, 2D, 3D), as well as interaction mechanics have to be part of the formula, in order to provide satisfying results to the users. The visualization has to enhance and support the user in completing the intended tasks, not to complicate and hamper the mission.

# Chapter 6

# THE MISSING PIECES OF THE JIGSAW ARE FALLING INTO PLACE

## 6.1 User-centered aspects

In the previous chapters of this dissertation, my contributions to the aspects *display technology*, *evaluation & user studies*, *interaction* and *visualization* have been introduced. Therefore the *puzzle pieces* have been introduced. In order to create *comprehensive approaches* the results have to be fused. A holistic view is essential to be able to create applications as well as work environments, suiting the needs of users.

In order to develop user-centered experiences, all relevant aspects have to be considered. As seen in Figure 6.1, the relationships evolving around users are complex and widely ramified. When developing applications, the user and the user's task, as well as expectations, have to be considered. The application should evolve around the user and provide support in accomplishing an user specific goal. This goal as well as general user expectations have to be formulated and carefully integrated.

Providing a first responder in a crisis area with a Virtual reality application, tailored to a CAVE, most likely will not lead to satisfying results, in terms of usability. *The hammer has to match the nails*, or generally speaking, the tools have to match the task. In order to design and to implement user-centered applications and user-centered work environments, a holistic view has to be applied.

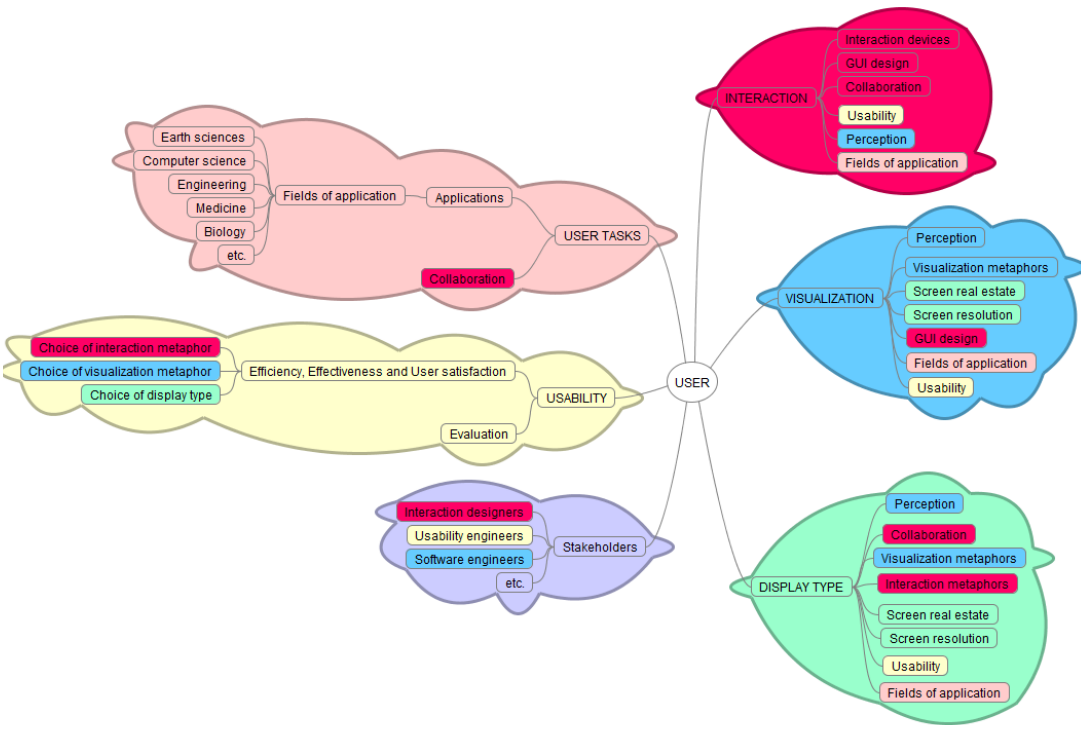



Figure 6.1: An excerpt of a network of relationships and correlations [Ole12].

The following three examples point out how choice of display, choice of interaction method and the choice of visualization contribute in creating user-centered applications, addressing user specific needs and adding value to usability. A holistic view is essential, to be able to develop comprehensive approaches, suiting the user's needs and also recognizing usability standards.

## 6.2 Tiled display walls as collaborative work environments for Public Participation

The traditional, well known *fields of application* for multi-display setups and tiled display walls have been those, where information had to be monitored: control rooms, air traffic control, traffic control, just to name a few. The number of displays clearly related to the task, in order to be able to display all the relevant information. User interaction as well as collaboration in front of the displays has not been in the focus, when implementing these kind of setups.

Medicine also can profit from tiled display solutions, facilitating the visualization of large datasets for comparison (e.g. Magnetic Resonance Images, MRI) and data mining. The spatial memory of the users is enabled and common or different features within the datasets are detected more easily.

In this section an example out of the field of urban, spatial and environmental planning is described, because it is an acute problem, which has to be addressed. The ongoing discussion about public participation, especially during the planning processes of large-scale projects, was brought up to a broad public again in 2011, with the *Stuttgart 21* incidents. Although there have been Public Participation back in 1997, many people did not agree with this specific large-scale project. So one has to ask the question, if the Public Participation implemented back in 1997, to stay with the example of the *Stuttgart 21* case, has not been implemented in a way to address the needs of those involved. How can these processes, involving a diverse group of actors, be improved?

The requirements from legislature to planning are becoming tremendously more complex; explicitly meaning that the contents to be considered and the people involved, are steadily increasing.

In Germany, Public Participation is implemented in the national building code law, in §§ 3 & 4 Baugesetzbuch (BauGB), to ensure the rights of the public, to provide basic democratic principles and to make complex planning processes transparent. The general public who is affected by planning decisions and future building projects is participated according to § 3 BauGB. Also involved are authorities, which also have to be integrated into the planning process. This is regulated by building code law, defined by § 4 BauGB. During Public Participation one has to consider the diverse backgrounds of those involved. Basic democratic principles are already implemented, since required by law, but execution still is lacking.

Computer Science can be used to support and to facilitate Public Participation processes. Facilitating by providing adequate information, accessible & understandable for both public and authorities. With recent technological developments, environments for collaboration instead of just a bare presentation can be provided (instead of focusing on the principle of *teacher-centred teaching*: the presentation of a building project and limiting the audience's interaction).

A framework of *democratic design criteria* is presented by Day [Day01]. Basic challenges, like embedding these criteria into the community networks are pointed out. Hanson and Karam [HK01] also focus on using community websites for communication and public announcements in order to save public funds (e.g. avoiding of printing flyers) and also reaching the majority of the community.

Kwartler [Kwa06] introduced three examples of Public Participation and the positive effects during the planning processes.

Another example is the Jordanian Hashemite Fund for Human Development (JOHUD [1]): *"The poor have a right to be involved in decisions that affect their lives. JOHUD helps their voices to be heard and uses its own influence to advocate on their behalf."*

Advances in information and communication technologies (in Germany: Informations- und Kommunikationtechnik, *IuK*) can provide a solid basis to make contributions to the field of planning support as well as public participation.

One of the main advantages of tiled display environments over usual desktop work spaces (traditional single space work environments) is the possibility to visualize and present large datasets. Users can view the entire dataset, so that permanent zoom & pan operations are not necessary. Therefore interaction with the display is more natural and intuitive. If a more detailed view is needed, the users can physically navigate to the point of interest by approaching the screen area that contains the

[1] http://www.johud.org.jo

desired high resolution information. This way a larger number of users can access the same information at the same time, making it possible for them to discuss their thoughts face-to-face. This kind of physical interaction is comfortable, even for inexperienced/non-expert users, which might be an important factor for utilizing tiled display environments for public participation projects.

The information of a large database (compare chapter 5.3) is visualized on the HIPerWall. Users are able to compare different databases at a glance, without the need of switching between multiple windows. In this way information can be analysed and discussed immediately by multiple users. This feature makes large high resolution displays applicable for decision support, wherever planners have to find consensus, like discussing planning alternatives or showing planning alternatives to stakeholders and community members. In this way participatory planning can be more fruitful, because face-to-face discussions are enabled by both choice of display type and interaction metaphor, allowing for an immediate exchange of experience [OTM+09].

Tag-based interaction with mobile devices allows for an intuitive user interaction with tiled display environments running the Google Earth applications [TMM+09].

Tiled display environments help users to process complex information more easily. The perception of the displayed information is improved; the interaction with the dataset can be reduced to a minimum by using natural physical navigation metaphors. So the user can concentrate to explore the data shown on the screens instead of investing resources to access the desired information [OML+09], [OTM+09].

Adequate visualization techniques also improve perception and therefore accessibility of visualized content. 3-dimensional representations of abstract data in a real world context support users to achieve fast impressions of database contents and also to recognize relative patterns and hidden correlations within the data. Visualizing database contents can be used to support participatory planning, in order to enhance public participation and to facilitate problem solving and decision-making in collaborative work environments [MGH+09].

The careful synthesis of *choice of display* (tiled display wall to allow for collaboration collaboration and as a basis to visualize high resolution data), *suitable visualization* (ease of access & understanding) and *intuitive interaction metaphors* (human zoom, face-to-face collaboration, tag-based interaction with mobile phones) create an user-centered environment, or user-centered application, tailored to support the users in accomplishing their tasks.

## 6.3 Public Display Systems

With public displays two application scenarios have been addressed, in order to provide users with a carefully designed architecture to support them in everyday tasks (DIP) and also more specific tasks (DIPP).

With Digital Interactive Pinboards (DIP) [TCO$^+$10], a modernized version of public billboards is introduced. DIPs serve as meeting points in *hot spot* locations. They are used to collect and distribute information, in and office environment e.g. news, announcements, lecture slides, recent papers.

Users can interact with the public display with their own mobile device, allowing them to browse content and download and save information of relevance on their mobile device. The simple structure of both server and client GUI support users in their interaction tasks: DIP serve as digital bulletin boards, so the information should be readily available, without long interaction.

The devastating *Tohoku earthquake*, Japan (2011), triggering a tsunami, which then caused the catastrophic failure of numerous nuclear power plants, revealed the critical need for adequate support architectures for arriving aid personnel. With recent natural disasters in mind, the public billboard approach has been enhanced and extended to suit the needs of first responders and aid personnel.

With first responders arriving on-site, the most crucial objective is the provision of recent information. The 2011 earthquake revealed, that disaster management has been fragile and inadequate, leaving arriving aid personnel without information and guidance.

The Digital Interactive Public Pinboard (DIPP) approach makes a fruitful contribution to these issues. It serves as a meeting point for arriving aid workers, providing up-to-date information, easy to access information and intuitive interaction possibilities.

The DIPP approach features a scalable and easy to set up client-server environment, providing aid personnel as well as citizen with up-to-date information. The combination of public display, computer, wireless network and the users personal mobile phones (serving as interaction & data storage devices) is an adequate approach to ensure mobility. A robust and reliable information architecture can be provided on-site, in no time, making the DIPP architecture ideal to react in situations, requiring fast responses.

Again, the careful synthesis of *choice of display* (public display to serve as a meeting point in a hot spot location), *suitable visualization* (ease of access & understanding in order to perceive important information) and *intuitive interaction metaphors* (mobile phone interaction, to be able to interact and store content on personal devices) support specific user needs. Especially in such critical application areas, like disaster management, the user-centered design is crucial, in order to make aid & rescue measures as effective and efficient as possible, by providing an adequate platform to distribute and collect information.

## 6.4 Virtual Reality Environments

Virtual Reality environments, like Cave Automatic Virtual Environments (CAVE), are niches. Both investment costs as well as follow-up costs (maintenance) limit the circle of potential users.

However, VR environments offer immersion, in areas where this can be regarded as an beneficial factor and users can profit from immersive 3D perception. In the field of earth sciences, where native 3D point cloud data is available, users can benefit from CAVEs. But CAVEs are not just environments to visualize content, users also have to be able to accordingly interact with the content.

In order to support geologists in conducting terrestrial LIDAR scans, a VR application has been developed to simulate the scans in VR. By simulating the scans in VR the geologists can determine the optimal position of the laser scanners by using aerial LIDAR data, thus improving the actual field work and getting a first virtual impression of features in the field. Multiple users can prepare a field trip (like a team of researchers), although one user has the lead, in interacting with the LIDAR scan simulation application.

3D can be helpful to convey information. Whereas maps can provide geo-reference by mapping information to a location, in 2D space (e.g. an earthquake), the epicentre of an earthquake might not be on the earth's surface, but rather beneath the earth's surface, visualizations in VR environments are able to convey this kind of information in an understandable way. In addition, VR environments still offer the *"aha-experience"*; thus making science tangible, for user groups like pupils.

## 6.5 Summary

The development of user-centered applications is not limited to the field of computer science and directly related disciplines (e.g. HCI). In order to create applications or, generally speaking, approaches and methods to support users in accomplishing tasks, interdisciplinary collaborations will become more important and be the decisive factor in advancing user-centered developments.

Today, most users of information and communication technology are not computer scientists, the majority of users are engineers, geologists, biologists, physicians, economists, just to name a few. During design, this has to be considered in terms of usability. The diverse user groups have to be considered, as well as the aspects of VIP.

The principle of VIP (**V**isualization, **I**nteraction, **P**resentation) [OCT$^+$10] combines partial aspects of computer science and proposes the careful synthesis of the aspects, therefore considering each aspect as an essential part, when creating user-centered experiences. A **holistic view** is promoted, instead of only considering isolated aspects.

An user-centered experience (which is not necessarily limited to software) should consist of the following criteria:

(a) ease of use

(b) intuitive & natural & logical interaction metaphors

(c) careful choice of interaction device

(d) comprehensible visualization finding the balance between loss of information and information overload

(e) careful choice of display

(f) synthesis of display, visualization and interaction has to be suitable to support the user to accomplish his tasks

(g) requirements and expectations of the user and the user's task

*Ease of use* is one of the most crucial aspects, especially when considering architectures, utilized by users with diverse backgrounds and consequential diverse levels of knowledge.

In order to appropriate for user-centered approaches, the discipline of Human-Computer Interaction (HCI) will gain of importance. In the field of computer science, HCI is a fairly young discipline, combining aspects of color theory, project management, psychology etc., in order to provide for an enhanced user experience. Today's users have expectations and are not satisfied with mediocre interaction mechanics or GUIs. The *march or die* mentality, handed down from software developers to users, is no more accepted. Computer science should provide the tools, to make non-computer science tasks more efficient, more effective and more user-friendly.

# Chapter 7

# CONCLUSION & FUTURE WORK

## 7.1 Conclusion

Like obvious processes in other academic disciplines, paradigm shifts also lead to a re-orientation in computer science. The user is coming back into the focus, terms like usability, human computer interaction, user experience, usability and user-centered applications are gaining importance. This thesis points out, that an isolated software or hardware solution often can't provide a satisfying answer for pressing questions and more often leave behind an overwhelmed user, not able to finish the tasks the computer scientists intended him to finish. A mutual understanding, a common language of computer scientists and users has to be developed. In order to develop user-centered experiences, providing real support and value to users, the focus has to become broader, considering all aspects, which are involved and therefore determining the user experience. Maeda [Mae06] presented "The Laws of Simplicity", revealing that less often is more, especially when considering intuitive HCI approaches.

Today computer science already is an interdisciplinary academic discipline, not only because it widely is used in other fields like architecture, mechanical engineering, aerospace engineering, earth sciences, and urban planning, just to name a few. Even within computer science itself there are parts of other disciplines already used and their utilization has to be refined. Aspects out of the fields of, e.g. color theory, perceptual psychology have to be applied in a more broad way.

Information and communication technologies are used in nearly all branches of today's life, both in the professional sector as well as in the private sector for fun and leisure. This shows one problem computer science faces today: diversity of users. Developers have to keep this fact in mind: users are not the typical user of applications, like it has been in the beginning of computer science. Users have become more diverse, with different levels of knowledge. Developers have to consider more variables for a successful implementation. Variables, for example, are: type of display, visualization approach, interaction device, and user. In this thesis we point out the significance of taking the aspects of presentation device, visualization metaphor and human computer interaction into consideration when designing applications, the so called VIP (Visualization, Interaction, Presentation) approach. In order to meet the needs and expectations of users, a holistic view has to be applied, and the fragments have to be put together, in order to achieve something complete.

With the *Tiled ++* approach a seamless LCD-based tiled display setup is introduced. Seamless in the sense of semantic loss, by addressing the french window effect, also known as the *bezel problem*. Users are now able to perceive a seamless picture without the typical problems of information loss (*overlay*) or deformed picture (*offset*). In addition, the evaluation conducted after implementation of *Tiled ++* proved how useful the added information is, especially during navigation tasks. Tiled high-resolution display walls also proved to be a fruitful option for collaborative work scenarios. They offer enough physical space, in order to let multiple users explore content, as well as interacting with the displayed content. The tag-based interaction featuring mobile devices, is one possible approach to interact with large, wall sized displays, enabling multiple users to interact with content and also enabling immediate face-to-face discussions. This is a crucial factor in the field of urban planning, where stakeholders with diverse backgrounds have to be integrated in the planning processes. Stakeholders can benefit from the synthesis of large display, intuitive user interaction and user friendly, easy accessible visualization during public participation processes, decision making and planning support.

In the field of public displays, capturing the idea of traditional billboards, new ways of deploying public displays in public spaces, *hot spots*, are demonstrated. In office environments public displays can be an alternative to paper and email notifications, providing ecological value and reducing network traffic by sending out mass emails. With a public display, a so called *Digital Interactive Pinboard* (DIP), users are able to share content in an office environment and pick up the information of interest, whenever they feel to. This approach returns the gift of self determination to users. With the DIP approach users can decide which information they want to share, to save and to download. Furthermore the *hot spot* location of the DIP can be a meeting point for social interaction. The *Digital Interactive Public Pinboard* (DIPP) is an advanced version of a public display, enhancing the basic principles of the DIP and offering an application tailored to suit the needs of first responders and citizens after natural or man-made disasters. The idea of deploying interactive public displays for disaster management derived from the fact that many first responders, especially after the Haiti and Japan earthquakes did find themselves lost after arrival in the airport. No one did coordinate and provide information to arriving helpers. With our DIPP system users are able to get basic information and also can interact with the public screens using their mobile devices and a wireless connection. Our approach combines the elements of deploying a display technology with elements of intuitive, straight forward user interaction (dual screen) and icon based visualization approaches to suit the needs of the diverse group of users. The straight forward and robust client-server approach ensures applicability even under harsh conditions.

For VR environments, an approach using the VRUI framework, therefore not limited to VR environments only, a tool to simulate terrestrial LIDAR scans was implemented. Terrestrial LIDAR scans are time consuming, since the laser scanners have to be set up in the field, in a proper way. The problem which can appear is *shadowing*, meaning the scanner's view is obstructed and therefore no point clouds for a specific area can be recorded. Contrary to this problem, *oversampling*, meaning to do more than needed scan tasks of a certain area, is also something one wants to avoid, since the hardware is expensive and scanning is time consuming. The LIDAR simulation tool addresses both problems by simulating the terrestrial scans in a virtual environment, based on lower resolution aerial LIDAR data, which has become commonly available. Users can choose from terrestrial scanner presets and simulate the scans, by doing so saving time and being able to get maimum benefits out of their actual field-trip time in the real world environment. Furthermore the GUI of the VRUI framework has been re-designed, based on the findings of a informal evaluation during the design process. The GUI prototype offers better scalability on arbitrary display environments and also addresses precision issues when using the flightstick for interacting in virtual reality environments, especially for GUI interaction (e.g. menu selection).

On the one hand it is important to ensure a certain scalability of approaches, on the other hand this can't be achieved in some cases. Scalability should enhance the user experience and not only look nice in theory.

However, advances in technology can not be seen as an universal answer for today's pressing questions. They only can offer support and open up new ways for the classic fields of computer science, namely visualization and also human computer interaction by providing a new tool-kit. Human computer interaction, a fundamentally interdisciplinary branch of computer science, will take on more significance. This derives from the fact of advances in both display technologies as well as interaction techniques and the paradigm shift to give attention to the most important part of the complex puzzle: the user. Computer scientist can't neglect the fact, that a variety of different users will use their implemented systems and that these users demand intuitive, scalable approaches to fit their needs. Therefore design studies, evaluations and early involvement of users will become a crucial factor in developing successful systems.

### Stepping on toes - A critical assessment

*"...you're not how much money you've got in the bank. You're not your job. You're not your family, and you're not who you tell yourself.... You're not your name.... You're not your problems.... You're not your age.... You are not your hopes."* [1]

This quote can be transferred to the field of computer science. A high resolution display environment will not solve pressing problems, nor will a new smart phone or

[1] Fight Club by Chuck Palahniuk, p.146, W. W. Norton & Company, New York, U.S.A., 1996.

tablet PC, although offering new interaction modalities. Devices can only provide support, offer a new set of tools to the users. Problems should not be designed around hardware, which is the case today (the famous *"we now have the hardware, let's think about how we can use it"*), the hardware solutions should be designed around the problems, in order to provide real benefits for people actually working with it. The users should get back into the focus of developers, being able to really express and communicate "their needs". Needs in terms of specifications, requirements, a PRD (product requirement document) [2] should be a standard. The IEEE SRS (software requirements specification) [3] provides a basic guideline. What one expects from industry, one should also expect from research and computer science.

In this doctoral thesis the example of LCD-based tiled display walls can be used to point out this dilemma. Tiled display walls offer several advantages, but also disadvantages. The advantages already have been pointed out in the previous chapters (e.g. enable physical navigation, enable spatial memory, enable collaborative work in front of the display, multi-user capabilities, suitable for interdisciplinary teams and applications, combining high resolution and large screen real estate) but does every application and every user need all these advantages? Tiled display systems still are expensive, considering the number of displays, the rack to be able to properly mount and physically align them, the render nodes driving the array of displays and also the maintenance factor. Although the Tiled++ approach is addressing a pressing research challenge by providing a nearly seamless LCD-based tiled display environment, the evaluation conducted during the research did point out a crucial finding, among the throughout positively feedback and evaluation results: in some application areas the bezel areas are not considered a disadvantage. In rapidly changing & dynamic environments, the negative effect of the bezels on users can be neglected. The decision on designing and finally implementing applications or creating new work environments has to be made individually, case-by-case.

Finally one has to be careful not to fall for *Cargo Cult Science* [Fey74], especially in the field of Computer Science and related disciplines. New visualization techniques, new display environments offering more and more resolution and screen real estate,

[2] DIN 69901-5.

[3] IEEE Guide to Software Requirements Specification. ANSI/IEEE Std 830-1984. IEEE Press, Piscataway/New Jersey, U.S.A., 1984.

and new hand held mobile devices can not and will not solve the questions mankind is facing today. These things can only provide small portions of relief in aiding the user's and provide support to the users, in order to solve problems as convenient as possible.

## 7.2 Future work

This dissertation provides insights on how users can benefit from the synthesis of arbitrary display technologies, visualization on these display technologies as well as interaction possibilities with these display technologies. In addition possible fields of application have been pointed out and described.

Large tiled display walls have been popular for digital signage and digital advertisement purposes. These purposes however are static, no user interaction is intended. In this thesis we presented ways how to add user interaction and integrate tiled display walls in scenarios out of the field of urban planning.

Based on the contributions made during the time of this thesis, the findings can be used as a basis for future research and improvements. Especially the field of interaction with mobile devices offers a variety of research topics. For example, what kind of interaction modalities, actual smart phones offer, can be utilized in a meaningful way to improve the user experience?

The results of the research done during the time of this PhD thesis can be seen as a foundation for future research. Interesting research fields are still open for further research, e.g. in the field of collaborative work in VR environments.

Although the VRUI middle ware offers a solid basis for collaborative work in VR, it can be enhanced and improved, especially regarding aspects of user interaction and in terms of usability. With the *ARC* metaphor a promising concept was developed, building a basis for further developments.

The field of collaborative work environments offers great potential to advance in the development of user-centered approaches. In the field of collaborative work environments open research challenges are in regard to file management approaches and version control, crucial issues when sharing one dataset for collaboration (two users manipulating one file).

Future developments should consider a holistic view and not just consider an isolated approach, e.g. from the field of visualization, trying to contribute to an problem.

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# BIOGRAPHICAL INFORMATION

## PERSONAL DETAILS

| | |
|---|---|
| Name | Peter Scott Olech |

## EDUCATION

| | |
|---|---|
| 10/2007 – 09/2012 | PhD student at the Department of Computer Science, Computer Graphics and HCI Group, University of Kaiserslautern, Germany |
| 10/2007 – 06/2012 | Member of the International Research Training Group (IRTG 1131) "Visualization of Large and Unstructured Data Sets - Applications in Geospatial Planning, Modeling, and Engineering" |
| 02/2011 – 03/2011 | Research visit at the University of California, Davis, CA, U.S.A. |
| 05/2010 – 06/2010 | Research visit at the University of California, Davis, CA, U.S.A. |
| 10/2008 – 11/2008 | Research visit at the University of California, Irvine, CA, U.S.A. |
| 03/2008 – 04/2008 | Research visit at the Arizona State University, Phoenix, AZ, U.S.A. |
| 2001 – 2007 | Study of *Spatial and Environmental Planning* at the University of Kaiserslautern, Germany<br>Degree: Diplom-Ingenieur (Dipl. -Ing.)<br>Diploma Thesis: "Requirements of *Urban Planning* for the development of virtual 3D city models - Methodology for the development of a virtual 3D city model" |
| 2000 – 2001 | Study of *Civil Engineering* at the University of Applied Sciences, Kaiserslautern, Germany |
| 1990 – 1999 | Staatliches Gymnasium Kusel, Germany |
| 1986 – 1990 | Grundschule Theisbergstegen, Germany |

## WORK EXPERIENCE

| | |
|---|---|
| 10/2007 – 06/2012 | Research and teaching assistant at the Department of Computer Science, Computer Graphics and HCI Group, University of Kaiserslautern, Germany (Lectures: Computer Graphics, Human-Computer Interaction, Computer Graphics for Architects and Engineers, CAD and Multimedia Systems.) |
| 12/2003 – 09/2007 | Teaching assistant at the Department of Computer Science, Graphical data processing and Visualization Group, University of Kaiserslautern, Germany (Lectures: Computer Graphics, Computer Graphics for Engineers, CAD and Multimedia Systems. Projects: Visualization of the World Cultural Heritage Völklinger Hütte, Völklingen, Germany; Visualization of Glocken Carré, Kaiserslautern, Germany; Visualization of University of Kaiserslautern and PRE-Uni-Park, Kaiserslautern, Germany.) |
| 05/2005 – 06/2005 | Internship at "Architekten und Ingenieure GmbH", Kaiserslautern, Germany |
| 08/2003 – 09/2003 | Internship at "Entwicklungsagentur Rheinland-Pfalz e.V.", Kaiserslautern, Germany |
| 08/2000 – 09/2000 | Internship at "Ingenieurbüro Feth GmbH", Ramstein-Süd, Germany |

# List of Publications


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[TCO+10] S. Thelen, D. Cernea, P. Olech, A. Kerren, and A. Ebert. D.I.P. - A Digital Interactive Pinboard with Support for Smart Device Interaction. In *Proceedings of the IASTED International Conference on Portable Lifestyle Devices (PLD 2010)*, Marina del Rey, CA, USA, 2010.

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[MGH+09] A. Middel, S. Guhathakurta, H. Hagen, P. Olech, and F. Hoepel. Visualizing Future 3D Neighbourhoods in Phoenix: An Application Incorporating Empirical Methods with Computational Graphics. In *M. Batty and L. Lui (Editors): Virtual Geographic Environments*. Beijing, China, Science Press, pp. 87 – 102, 2009.

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[TMM+09] S. Thelen, J. Meyer, A. Middel, P. Olech, A. Ebert, and H. Hagen. Tag-Based Interaction with Large High-Resolution Displays. In *Proceedings of the 4th IASTED International Conference on Human-Computer Interaction (IASTED-HCI)*, St. Thomas, Virgin Islands, USA, 2009.

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